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Availability of Critical Scrap Metals Containing Chromium in the United States

Superalloys and Cast Heat- and Corrosion-Resistant Alloys

By LeRoy R. Curwick, Walter A. Petersen, and Harry V. Makar

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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AVAILABILITY OF CRITICAL SCRAP METALS CONTAINING CHROMIUM IN THE UNITED STATES. SUPERALLOYS AND CAST HEAT- AND CORROSION-RESISTANT ALLOYS

by

LeRoy R. Curwick, Walter A. Petersen, and Harry V. Makar

ERRATA

Page 7, sixth line from the bottom should read as follows: category "Other" may in some cases represent a major portion of production,

Page 16, Table 15: The total for the column headed "Grindings" should be 7.9.

Page 16, Table 15, Footnote 2 should read as follows: Grand total: 317.5 million pounds.

Page 24, Table 21, Footnote 4 should read as follows: Grand total: 104.9 million pounds of scrap containing 18.9 million pounds of chromium.

Page 25, Table 22, Footnote 2 should read as follows: Grand total: 19.7 million pounds of scrap containing 3.3 million pounds of chromium.

Page 34, second line should read as follows: industries, it is clear that more comprehensive and specific data are required.

AVAILABILITY OF CRITICAL SCRAP METALS CONTAINING CHROMIUM IN THE UNITED STATES

Superalloys and Cast Heat- and Corrosion-Resistant Alloys[1]

by

LeRoy R. Curwick,[2] Walter A. Petersen,[3] and Harry V. Makar[4]

ABSTRACT

This Bureau of Mines report presents the results of a study conducted to assess the domestic availability of chromium from superalloy and cast heat- and corrosion-resistant alloy scrap material. Six alloy classes included in this survey were investment cast, hardfacing, and wrought nickel- and cobalt-base alloys, wrought nickel-iron-base alloys, and heat- and corrosion-resistant alloy castings. Data were collected for 1976 on metallic scrap generation, use patterns, and production practices for these alloy producing and using industries. A model was developed that allowed an assessment of the materials flow circuits within the industries that produce these alloys. The types, amounts, sources, secondary products, and ultimate destinations of chromium-containing metallic scrap for the six alloy classes were determined. Regarding the overall recycling efficiency of these alloy producing and using industries, of the 580.9 million pounds of scrap generated from these six alloy classes in 1976, about 72 percent (416.8 million pounds) was remelted by the same alloy-producing industries, about 18 percent (104.9 million pounds) was downgraded into stainless and low-alloy steels, about 3 percent (19.7 million pounds) was exported, and about 7 percent (39.5 million pounds) was lost through landfill or other disposal or service wastage. The lost material is primarily contaminated oxides for which recovery is currently uneconomic. However, the 124.6 million pounds of scrap material downgraded or exported in 1976 contained potentially recoverable critical strategic elements. The amount of scrap material lost to the six alloy-producing industries in this manner contained 22.1 million pounds of chromium, 53.4 million pounds of nickel, 5.9 million pounds of cobalt, 35.9 million pounds of iron, and 7.3 million pounds of other alloying elements.

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[1]This report was prepared by Inco Research & Development Center, Suffern, N.Y., under Bureau of Mines Contract J0188056.

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INTRODUCTION

There is growing concern that nonmarket factors may affect the price and availability of many of the metals used for military and other high-technology applications. Chromium (Cr) is of particular concern because the major ore bodies are concentrated outside the United States in areas that may be subject to political disruption. Chromium is technologically important and has no substitutes for the most critical applications. Other metals of concern are cobalt (Co), nickel (Ni), tungsten (W), molybdenum (Mo), columbium (Cb), and tantalum (Ta). All of these metals are used in substantial quantities in the alloy classes covered in this study; that is, in nickel-, cobalt-, and nickel-iron-base alloys and to a lesser extent in heat- and corrosion-resistant alloy castings. The chromium supply and consumption situation was recently reviewed in detail (<u>1</u>).[5]

The industries covered in this study can be categorized as "producers," "fabricators," "manufacturers," "users," and "recyclers"[6] of the alloys mentioned above. In general, the major participants are high-technology companies which are conscious of product quality requirements and which work closely with user companies on materials problems. These industries already use as much available scrap as they can within the metallurgical limits imposed by product quality specifications and furnace operating practices.

The most acceptable, least costly, highest quality scrap for the alloy producer is "home scrap." Home scrap is generated during the "raw material" melting to "primary product" production phase by the alloy producer industries. Home scrap consists of "solids," "turnings," "grindings," "skulls," "spills," "slags," "scales," and "dusts." In general, all home scrap solids and turnings are reused internally to make up a large portion of the raw materials for the "melt charge." The grindings and "mixed melt shop scrap" (skulls and spills) are mixed with oxides and are usually sold for refining and eventual use for steelmaking. Dusts, scales, and slags are contaminated and undesirable for existing recycling systems and thus are largely discarded.

"Prompt industrial scrap" consists of solids, turnings, grindings, "sludges," and "liquors" generated by fabricators and manufacturers during the primary product to "finished product" phase of equipment manufacture. Most alloy producers use some prompt industrial scrap in the raw materials charge for melting. This material is generally in the form of solids purchased either directly from the manufacturing source or indirectly through recyclers.

"Obsolete scrap" is generated by users and recyclers when used equipment is overhauled and parts replaced, through "service wastage," and when equipment is dismantled at the end of its useful "life cycle." The usable scrap generally occurs as solids and grindings. The generation of obsolete scrap occurs over the entire life cycle of the equipment and thus introduces a time scale variable into this study.

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[5]Underlined numbers in parentheses refer to items in the bibliography preceeding the appendixes.

[6]Terms in quotation marks are defined in appendix A.

It is common practice in the alloy melting industry to make maximum use of scrap as a raw material for melting. This is done because scrap metal is usually less expensive than primary metals and sometimes more readily available. Qualitative information on generation and use of valuable scrap metal by the chromium alloy producing and using industries exists in the literature (3-4). However, a comprehensive quantitative study has not been done. This study was undertaken to fill this need. The principal objective of the study was to assess the domestic availability of superalloy and cast heat- and corrosion-resistant alloy scrap. Information to be developed included types, quantities, sources, secondary products, and ultimate destinations of scrap for the alloy classes mentioned previously. A companion study (7) deals with chromium-containing wrought stainless steel and heat-resisting alloy scrap.

A secondary objective of the study was to provide data that could be used to estimate the quantity and quality of superalloy and cast-heat and corrosion-resistant alloy scrap that could be used for chromium recovery processes. Such processes are being developed under separate contracts. The processes under development will refine metallic scrap and produce pure chromium, nickel, and cobalt and other metals of a quality suitable for recycling to the original alloy producers or to other high-value uses. The implications of the results of the scrap study will be discussed in separate reports dealing with the development of these processes. The current study and the process development research were sponsored by the Federal Emergency Management Agency (formerly Federal Preparedness Agency) through the Bureau of Mines, U.S. Department of the Interior.

METHODS AND ASSUMPTIONS USED FOR THE STUDY

Model

It was recognized that it was not possible to gather complete and reliable data on all phases of the alloy producing and using industries. Therefore, a "model" of these industries was developed which, given available data and reliable estimates of overall industry practices, would allow derivation of the information required to meet the objectives of this study.

The model used is shown in figure 1. This is a materials flow diagram which follows the alloys from the raw materials stage through the primary and finished product stages to obsolescence. Once the model was completed for the six alloy classes covered in the study, it was possible to address the study objective. A detailed description of the model is contained in appendix B.

The numerical data for the flow diagram were developed in the following manner: First, the quantity of primary product was estimated from available data for the six alloy classes. The raw materials to primary product cycle was filled in, using available information on "production efficiency," relative proportions of materials in the melt charge, and relative quantity and type of home scrap generated. The primary product to finished product and finished product to obsolescence cycles were filled in by estimating the quantity and forms of scrap generated at each stage.

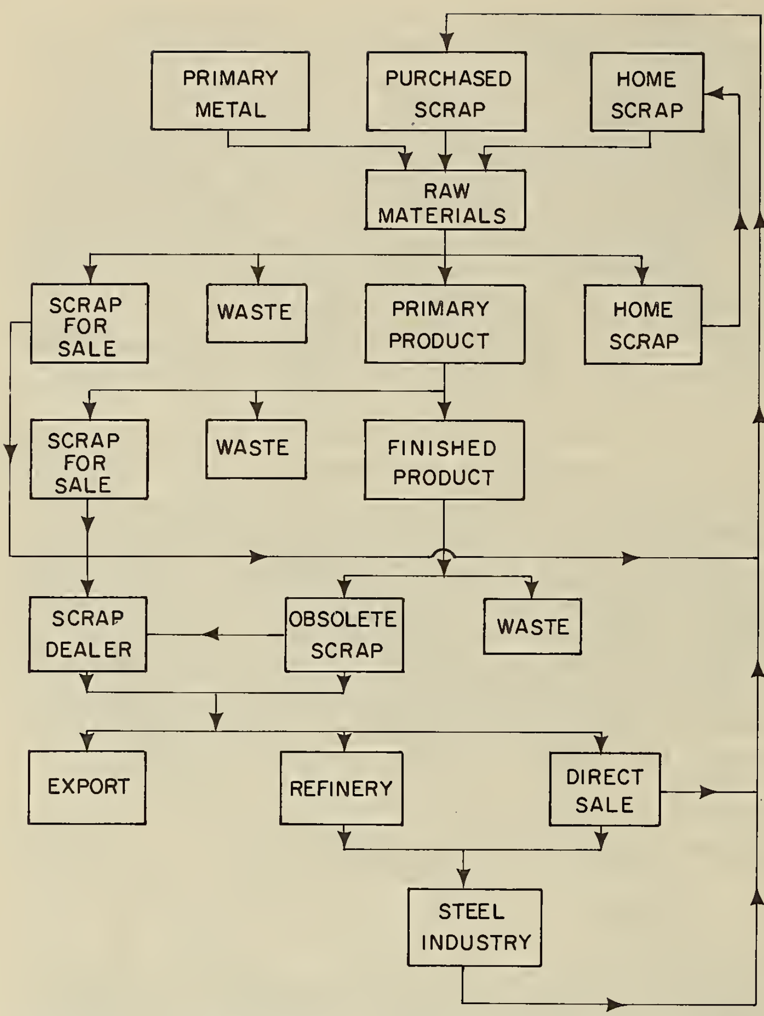


FIGURE 1. - Materials flow circuit used for production model.

Once the model was completed, its accuracy was verified by comparing predicted quantities with data from independent sources, such as chromium consumption figures and scrap exports.

Definition of Alloys

Alloys included in this study were the chromium-containing nickel-, cobalt- and nickel-iron-base alloys and heat- and corrosion-resistant alloy castings. These generic alloys were divided into six broad classes whose alloy composition ranges are shown in table 1. The alloy classifications adopted do not correspond precisely to those used in other industry and Government reports. They were carefully selected to encompass products of distinct alloy-producing industries. These classifications greatly simplified development of the production model and facilitated understanding of the scrap flow patterns. Tables with the nominal compositions of some specific alloys that fall within these broad classes appear in appendix C. These tables cover the major alloys of the classes shown. Note that certain alloys may appear under two classes if they are produced in two product forms (cast and wrought). Note that the term "superalloy" was not used to designate an alloy classification because it was considered to be too restrictive and imprecisely defined. Three of the six alloy classes listed in table 1 (classes 1, 3, and 4) comprise the alloys that are considered by most, but not all, alloy producers to be superalloys. As noted above, the classes were defined more by producing industry than alloy composition. Thus, alloys listed within a given class are often produced by similar techniques for use in similar components. Using this classification scheme, the type and relative quantity of scrap generated can be more readily defined. Comments concerning the industries and production methods that help to distinguish the classes follow:

1. Investment Cast. Cast alloys used primarily in gas turbine components. Usually made by two-step manufacturing method consisting of production of master melt ingot and then remelting for casting to shape. These alloys are melted in relatively small furnaces and have the most stringent purity requirements of the six classes.

2. Hardfacing Cast. Alloys produced in the form of powders or rods for subsequent use for hardfacing of metal components.

3. Wrought Nickel- and Cobalt-Base. Alloy production characterized by casting of ingots which are hot-worked to bar, sheet, plate, or wire. Extensive use of AOD refining by this industry permits use of lower purity raw materials than for investment cast alloys of similar nominal composition.

4. Wrought Nickel-Iron Base. Production methods and product forms very similar to previous category. These alloys are often made by stainless steel producers who may not make wrought nickel alloys. Also, scrap that is high in iron cannot be used in those alloys.

5. Heat-Resistant Alloy Castings. Alloys in this category usually contain carbon for strengthening, and components are made by centrifugal casting (tubes) or sand casting (furnace hardware).

6. Corrosion-Resistant Alloy Castings. Alloys are normally made by companies specializing in casting components for handling corrosive fluids. The procedures and alloy compositions are generally similar to those used for heat-resistant castings.

TABLE 1. - Nominal composition ranges of the classes of alloys studied[1, 2]

Alloy class	Composition, percent								Melting method[3]
	Cr		Ni		Co		Fe		
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
1. Investment cast nickel- and cobalt-base.	5	30	0	75	0	70	0	20	a, b
2. Hardfacing cast nickel- and cobalt-base.	5	30	0	75	0	70	0	20	b, a
3. Wrought nickel- and cobalt-base...	15	25	0	80	0	80	0	20	c, a, b
4. Wrought nickel-iron-base..........	12	30	10	45	0	20	25	55	c, a, b
5. Heat-resistant alloy castings.....	15	30	5	35	0	0	39	88	b, c
6. Corrosion-resistant alloy castings	10	20	0	30	0	0	39	88	b, c

[1]A few alloys that fall outside these ranges are undoubtedly included in the available statistics; however, these definitions account for a large majority of the alloys covered.

[2]Individual alloys may contain substantial quantities of additional elements including molybdenum, tungsten, columbium, tantalum, hafnium, titanium, aluminum, manganese, and silicon. See appendix C for actual compositions.

[3]Listed in order of relative importance.
a--Vacuum.
b--Air induction.
c--Electric arc furnace plus argon-oxygen decarburization.

Sources of Information

Data on alloy production, melt charge make-up, scrap generation, and scrap disposition were gathered from a wide variety of sources including unpublished information, open literature, and verbal responses to direct industry inquiries. The authors had access to the market research efforts, purchased surveys, and in-house industry-related expertise of The International Nickel Co., Inc. The following were available from the literature: trade association reports, Government statistical reports, and Government-sponsored surveys and reports related to nickel alloy utilization, scrap generation, and disposition. The general literature sources used in this study are listed in the bibliography.

Because 1976 was the year for which we had the most complete set of data on alloy production and distribution, it was chosen as the base year for this study. It is recognized that 1976 was an atypical year in that alloy production was lower than normal. Consequently, where pertinent, reference in the discussion is made to the situation expected for normal and high-production years.

A survey was conducted, by telephone or personal interview, of technical or purchasing personnel of 53 organizations involved in producing or using the alloys covered by this study. This was done to obtain data for this report and to verify derived data and conclusions. The organizations contacted are listed in appendix D. This list is not totally inclusive but is a representative sample of the industry.

Reliability

Most of the data contained herein are estimated or derived, since there is no mandatory reporting of this type of information by producers, manufacturers, or scrap processors. Also, there are significant differences in production practices and terminology between various companies. Furthermore, in those reports that are available, there is considerable variation in the alloy industry and product nomenclature. Industry contacts were asked to give an overall assessment of their industry. The responses showed a 20-percent range in the estimates of scrap generated and utilized. Based on the variability found in the estimates of the quantity of product produced in each alloy class, an error of ±20 percent was estimated.

Rounding

Numbers contained in the data tables were rounded to the nearest tenth (generally percent or million pounds). Thus, some small inconsistencies may appear in the data tables due to rounding error.

Assumptions

Several assumptions were made with respect to the disposition of prompt industrial and obsolete scrap. Most of these assumptions were based on responses to our industry survey. They represent widely accepted industry views on scrap materials disposition on which specific data were not available.

In the absence of quantitative data from scrap recyclers, it was assumed that only "identified" clean, solid scrap would be purchased by the alloy producer to make up the "purchased scrap" portion of the melt charge. Solids would be preferred over turnings for this purpose. It was also assumed that scrap was only recycled within the same alloy class. This was done to simplify the analysis, although some interchange takes place. The effects of this assumption on the results of the model are discussed in a later section.

It was assumed that half of the remaining solid prompt industrial and obsolete scrap was exported and half was recycled within the United States as a charge material for stainless steel, cast iron, and low-alloy steel. The assumption that chromium-containing alloy scrap is exported was substantiated by study responses and by inference from Bureau of Mines statistics on related generic alloy classes.

It was assumed that only the highest quality chromium-containing alloy scrap not being fully utilized by U.S. industries would be exported. Therefore, it was assumed that essentially all of the prompt industrial scrap turnings are recycled to the U.S. industries mentioned above. It was further assumed that grindings and mixed melt shop scrap (sometimes referred to as "refinery-grade scrap") are reprocessed for use in the U.S. steel industry because they are unsuitable for export or direct use in the melt charge and require special refining.

Information Gaps

The largest single information gap occurs with respect to the disposition of the large quantity of prompt industrial and obsolete scrap which is handled by the scrap dealers, reprocessors, and secondary refiners. This is a highly competitive industry, and quantitative responses to our inquiries were not forthcoming. Clearly, a broadly based survey of this industry would fill a major information gap. A representative of the National Association of Recycling Industries stated that the association did not keep separate statistics on the materials covered by this study.

RESULTS

Alloy Production

Estimates of 1976 production of primary product were made for the six alloy classes defined in table 1. These production figures are the baseline data used to calculate the additional data on raw materials and scrap generation and disposition needed to complete the model. Estimates of production for individual alloys within each alloy class are listed in tables 2 to 7. Estimates are shown only for the most widely used alloys. Although the category other may in some cases represent a major portion of production, this classification includes many alloys that are produced in relatively small quantities.

To assess the historical trends in alloy production and the quantity of obsolete scrap available, data were acquired on primary product sold over the period 1958-78.

TABLE 2. - Estimated production of primary product for investment cast nickel- and cobalt-base alloys in 1976[1]

Alloy designation	Quantity, million pounds	Percent of subtotal
Nickel-base alloys:		
Alloys 713C and 713LC	5.0	28.6
B-1900+Hf	2.0	11.4
RENÉ 77	2.0	11.4
INCONEL alloy 738	1.5	8.6
INCONEL alloy 718	1.0	5.7
Other	6.0	34.3
Subtotal	17.5	100.0
Cobalt-base alloys:		
X-40	2.0	34.8
FSX-414	1.0	17.4
WI-52	1.0	17.4
Other	1.75	30.4
Subtotal	5.75	100.0
Total	23.25	NAp

NAp Not applicable.
[1]Alloy compositions contained in table C-1.

TABLE 3. - Estimated production of primary product for hardfacing cast nickel- and cobalt-base alloys in 1976

Alloy designation	Quantity, million pounds	Percent of total
Nickel-base cast rod[1]	0.6	7.4
Nickel-base powder[1]	1.8	22.2
Cobalt-base cast rod[2]	4.3	53.1
Cobalt-base powder[2]	1.4	17.3
Total	8.1	100.0

[1]Average composition, in percent: 59.5 Ni, 16 Cr, 8 Mo, 4 W, 5 Fe, 4 Si, 3 B, 0.5 C.
[2]Average composition, in percent: 52.8 Co, 5 Ni, 29 Cr, 2 Mo, 6 W, 3 Fe, 1 Si, 1.2 C.

TABLE 4. - Estimated production of primary product for wrought nickel- and cobalt-base alloys in 1976[1]

Alloy designation	Quantity, million pounds	Percent of total
WASPALOY	10	11.1
INCONEL alloy 718	10	11.1
INCONEL alloy 600 series	20	22.2
INCONEL alloys 750, 751	6	6.7
INCONEL alloy 700 and UDIMET alloys 500, 700	10	11.2
RENE 41, 95	5	5.5
HASTELLOY alloy X	2	2.2
HASTELLOY alloy C-276	2	2.2
Other	25	27.8
Total	90	100.0

[1]Alloy compositions contained in table C-2.

TABLE 5. - Estimated production of primary product for wrought nickel-iron-base alloys in 1976[1]

Alloy designation	Quantity, million pounds	Percent of total
INCOLOY alloys 800, 801, 802, 825	16	34.8
INCOLOY alloys 901, 903	10	21.7
A-286	5	10.9
ARMCO 20-45-5, V-57, N-155, RA-330, PYROMET 860	10	21.7
Other	5	10.9
Total	46	100.0

[1]Alloy compositions contained in table C-3.

TABLE 6. - Estimated production of primary product for heat-resistant alloy castings in 1976[1]

Alloy designation	Quantity, million pounds	Percent of total
HK	20.2	38
HH	11.2	21
HT	8.0	15
HC	3.7	7
HP	2.1	4
HU	2.1	4
HN	1.5	3
HL	1.1	2
HF	1.1	2
HD	1.1	2
Other	1.1	2
Total	53.2	100

[1]Alloy compositions contained in table C-4.

TABLE 7. - Estimated production of primary product for corrosion-resistant alloy castings in 1976[1]

Alloy designation	Quantity, million pounds	Percent of total
CF-8M	51.8	47
CF-8	11.0	10
CA-15	9.9	9
CN-7M	6.6	6
CB-30	6.6	6
CA-6NM	3.4	3
CF-3M	3.3	3
CD-4MCu	3.3	3
CF-8C	2.2	2
CA-40	2.2	2
Other	9.9	9
Total	110.2	100

[1]Alloy compositions contained in table C-4.

For nickel-, cobalt-, and nickel-iron-base alloys, no data are available on historical production. Most relevant are the nickel consumption data from the Bureau of Mines Mineral Industry Survey (10), but even these present problems, since nickel consumption is reported for various alloy classes that are not precisely defined and that do not correspond to the alloy classes used in this survey. In addition, the alloy classifications used by the Mineral Industry Survey have changed three times over the past 20 years. This made it difficult to estimate historical production data for the alloy classes covered for this study. Instead the nickel consumption data for 1958-78 for the Mineral Industry Survey alloy classifications that are most nearly related to the four nickel-, cobalt- and nickel-iron-base alloy classes covered in this study were used to estimate alloy production figures. These data are given in table 8 and plotted in figure 2. It was assumed that the primary product growth rate for these four alloy classes followed the same growth rate as the nickel consumption statistics. This annual average growth rate is 2.1 percent over the period 1958-78.

TABLE 8. - Annual primary nickel consumption (10) for superalloys, other nickel and nickel alloys, cast nickel alloys, wrought nickel alloys, high-temperature and electrical resistance alloys, and nonferrous alloys, 1958-78

(Million pounds)

Year	Super-alloys	Other[1]	Cast nickel alloys	Wrought nickel alloys	HT and ER[2]	Nonferrous[3]	Total
1958	NC	NC	NC	NC	14.5	28.5	43.0
1959	NC	NC	NC	NC	20.8	40.4	61.2
1960	NC	NC	NC	NC	19.8	42.3	62.1
1961	NC	NC	NC	NC	21.7	45.7	67.4
1962	NC	NC	NC	NC	24.4	43.2	67.6
1963	NC	NC	NC	NC	26.1	38.1	64.2
1964	NC	NC	NC	NC	28.9	35.4	64.3
1965	NC	NC	NC	NC	34.4	56.7	91.1
1966	NC	NC	NC	[4]91.5	10.8	NC	102.3
1967	NC	NC	7.1	74.2	8.6	NC	89.9
1968	NC	NC	13.2	66.8	7.8	NC	87.8
1969	22.8	52.7	NC	NC	NC	NC	75.5
1970	21.8	70.1	NC	NC	NC	NC	91.9
1971	13.5	53.6	NC	NC	NC	NC	67.1
1972	22.2	56.0	NC	NC	NC	NC	78.2
1973	22.6	74.9	NC	NC	NC	NC	97.5
1974	22.2	85.8	NC	NC	NC	NC	108.0
1975	11.4	72.3	NC	NC	NC	NC	83.7
1976	15.5	61.6	NC	NC	NC	NC	77.1
1977	19.6	60.7	NC	NC	NC	NC	80.3
1978	27.1	76.1	NC	NC	NC	NC	103.2

NC Not categorized.
[1]Other nickel and nickel alloys.
[2]High-temperature and electrical resistance alloys.
[3]Nonferrous alloys less 15.8 percent for copper base alloys.
[4]Cast and wrought.

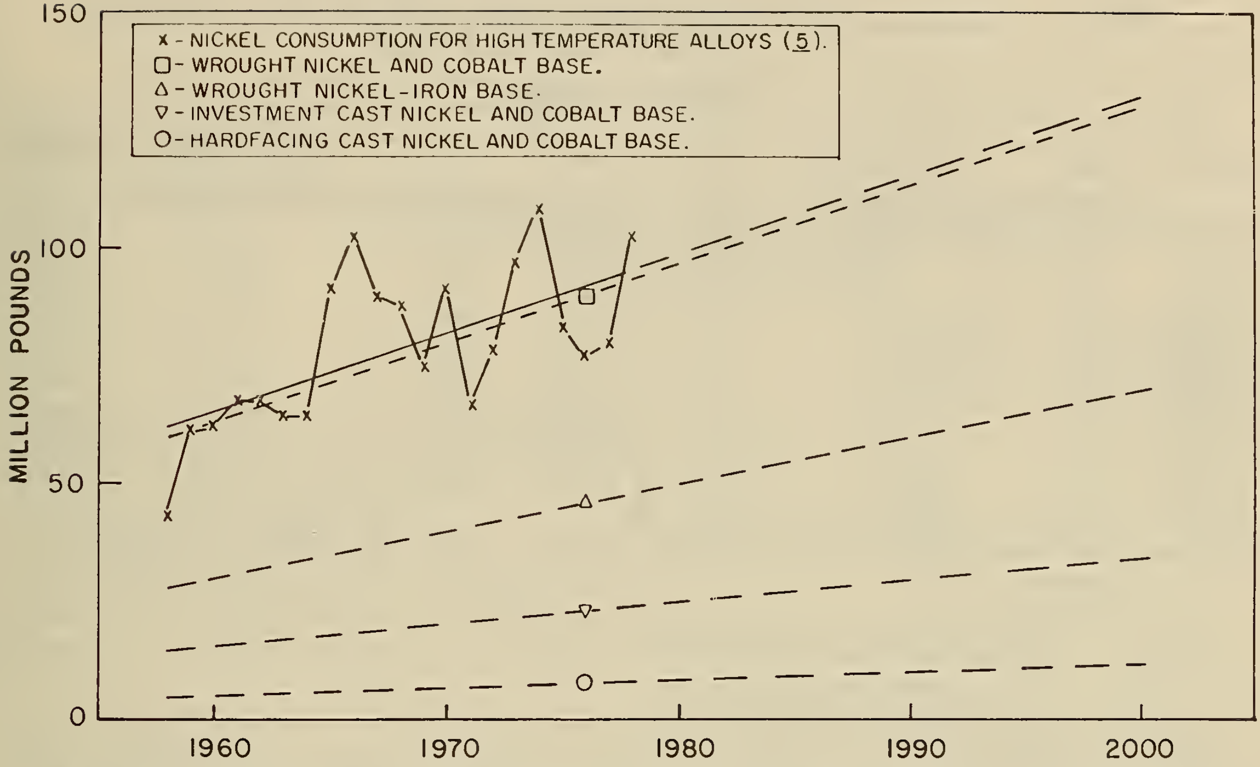


FIGURE 2. - Annual primary nickel consumption for high-temperature alloys, 1958-78 (10). Estimated primary production growth curves for investment cast, hardfacing cast, and wrought nickel- and cobalt-base alloys (dashed lines).

The quantity of primary product produced for heat- and corrosion-resistant alloy castings was compiled by the American Iron and Steel Institute and based on estimates provided by the U.S. Bureau of the Census (9) is given in table 9. Figure 3 shows the production of primary product for heat- and corrosion-resistant alloy castings over the 20-year period 1958-78 and indicates probable trends for the near future.

TABLE 9. - Annual primary production of heat- and corrosion-resistant alloy castings, 1958-78

(Million pounds)

Year	Heat resistant	Corrosion resistant	Total	Year	Heat resistant	Corrosion resistant	Total
1958	38.7	41.3	80.0	1970	47.2	97.8	145.0
1959	36.1	36.2	72.3	1971	42.5	88.1	130.6
1960	35.0	36.8	71.8	1972	36.6	75.7	112.3
1961	33.5	40.9	74.4	1973	39.9	82.6	122.5
1962	37.3	44.9	82.2	1974	69.4	72.6	142.0
1963	40.8	49.1	89.9	1975	65.2	100.1	165.3
1964	41.4	60.0	101.4	1976	53.2	110.2	163.4
1965	41.1	85.2	126.3	1977	45.2	93.6	138.8
1966	55.8	115.7	171.5	1978	51.8	107.4	159.2
1967	52.5	108.7	161.2				

Source: Reference 9 and Inco internal reports (data for 1968 and 1969 not available).

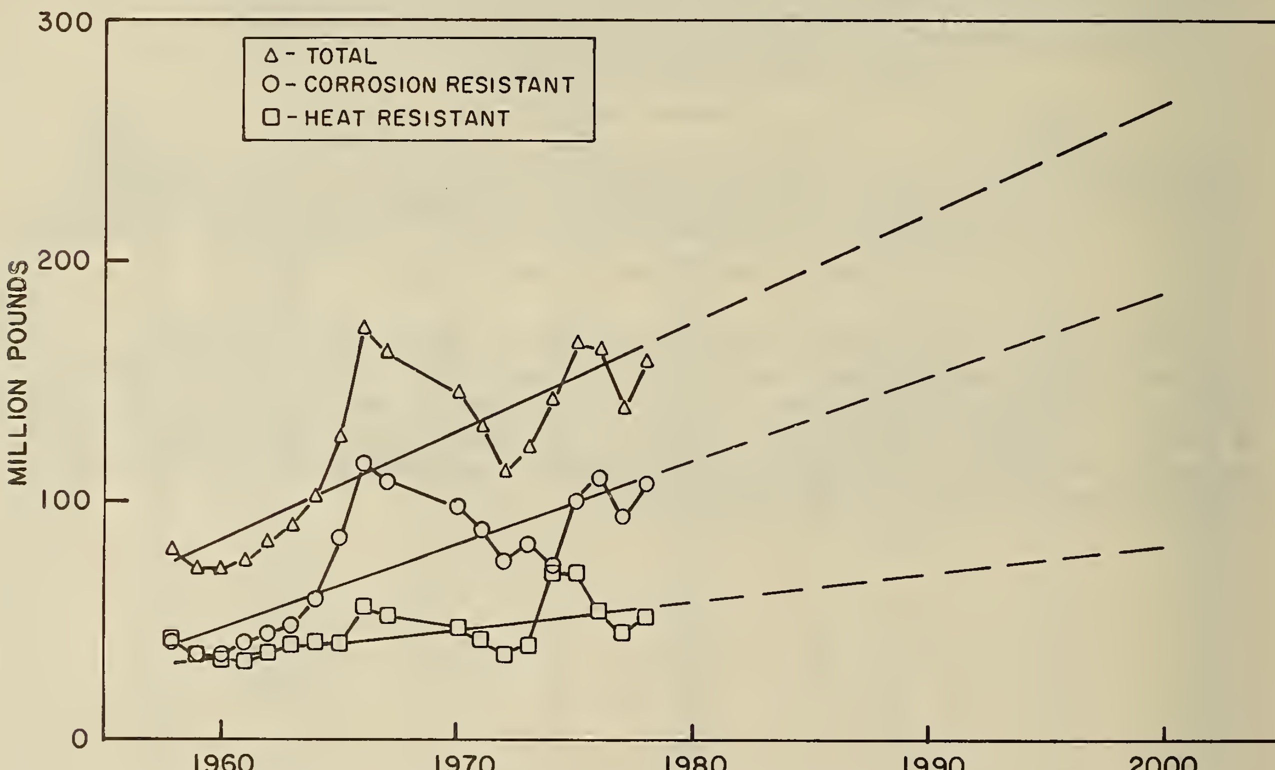


FIGURE 3. - Annual primary production for heat- and corrosion-resistant alloy castings, 1958-78 (9).

Production Efficiencies

Based on responses to this study, "production efficiency" for raw materials to primary product and for primary product to finished product was estimated. These values are listed for each alloy class in table 10.

TABLE 10. - Production efficiencies by alloy class for raw materials to primary product and for primary product to finished product

Alloy class	Primary product efficiency[1]	Finished product efficiency[2]
Investment cast nickel- and cobalt-base...........	80	40
Hardfacing cast nickel- and cobalt-base...........	79	60
Wrought nickel- and cobalt-base..................	50	54
Wrought nickel-iron-base.........................	50	54
Heat-resistant alloy castings....................	52	98
Corrosion-resistant alloy castings...............	47	98

[1]Ratio of primary product to raw material melted.
[2]Ratio of finished product to primary product expressed in percent.

The quantities of primary product produced for each alloy class (taken from tables 2 to 7) are listed in table 11, column 2. Using these data and the estimates of production efficiencies (table 10), the raw materials melted (column 1) and finished product produced (column 3) were derived and are shown in table 11.

TABLE 11. - Estimated production by alloy class in 1976[1]

(Million pounds)

Alloy class	Raw materials melted	Primary product	Finished product
Investment cast nickel- and cobalt-base...	29.1	23.3	9.3
Hardfacing cast nickel- and cobalt-base...	10.3	8.1	4.8
Wrought nickel- and cobalt-base...........	180.0	90.0	48.6
Wrought nickel-iron-base..................	92.0	46.0	24.8
Heat-resistant alloy castings.............	102.3	53.2	52.2
Corrosion-resistant alloy castings........	234.5	110.2	107.9
Total................................	648.2	330.8	247.6

[1]Derived from tables 2 to 7 and table 10.

Melt Charge Makeup and Scrap Utilization

In addition to production efficiencies, information on melt charge make-up was obtained through our study responses. Based on these responses, estimates were made of the percentage of "primary metal," home scrap, and purchased scrap used in the melt charge make-up for each of the six alloy classes. These percentages are given in table 12. Also given in this table are the quantities of raw materials that go into the melt charge make-up.

These quantities were calculated from the data of table 11 and the percentage estimates as shown in table 12.

TABLE 12. - Melt charge raw materials

Alloy class	Primary metal		Home scrap		Purchased scrap	
	Million pounds	Percent[1]	Million pounds	Percent	Million pounds	Percent
Investment cast nickel- and cobalt-base	13.0	45	2.4	8	13.7	47
Hardfacing cast nickel- and cobalt-base	6.5	63	0.8	8	3.0	29
Wrought nickel- and cobalt base	72.0	40	84.6	47	23.4	13
Wrought nickel-iron-base	36.8	40	43.2	47	12.0	13
Heat-resistant alloy castings	22.5	22	41.0	40	38.8	38
Corrosion-resistant alloy castings	54.0	23	105.6	45	74.9	32
Total[2]	204.8	32	277.6	43	165.8	25

[1]Percent of total raw materials for melt charge.
[2]Grand total: 648.2 million pounds.

To assess the economic forces affecting melt charge make-up, "producer" and selected "merchant" prices were obtained for primary metals and chromium-containing alloy scrap. This information is shown in tables 13 and 14. For comparison, primary metals and scrap quotations are shown for February and May 1979. Note that the primary metals and scrap markets were extremely volatile in mid-1979 owing to generally strong demand for metals and shortages of some elements. Cobalt and molybdenum prices were particularly volatile during this period. In addition to the quoted scrap prices shown in table 14, the metal value contained in these alloys was calculated based on the producer price for the contained elements. These values are shown for comparison.

TABLE 13. - Published producer prices of various forms of chromium and other selected primary metals in February and May 1979 (10,000-pound minimum lot size)

Material	Price per pound, dollars		
	1976 range	February 1979	May 1979
Low-carbon ferrochromium[1]	0.85- 1.00	0.75	0.85
High-carbon ferrochromium[1]	.41- .50	.42	.46
Chromium metal	2.44	3.10	3.20
Nickel pellets	2.20- 2.41	1.93	2.85
Ferronickel[2]	2.10- 2.34	1.75	2.80
Iron squares (4-inch)	.11- .13	.17	.17
High-quality steel scrap	.02	.06	.05
Cobalt, electrolytic	4.00- 4.90	25.00	[3]25.00
Molybdenum pellets	5.60- 6.85	10.51	[4]11.15
Titanium sponge	2.70	4.00	6.50
Aluminum ingot	.41- .48	.56	.58
Tantalum powder	35.40-48.00	67.35	82.50
Columbium pellets	18.00-25.00	55.00	55.00

[1]Per pound of chromium.
[2]Per pound of nickel.
[3]"Merchant" price--$37.50 per pound.
[4]"Merchant" price--$32.00 per pound.

TABLE 14. - Prices quoted for identified solid scrap[1] and calculated metal value for several alloys in February and May 1979 (10,000 pound minimum lot size)

Alloy designation	Alloy class	Price per pound, dollars			
		February 1979		May 1979	
		Quoted scrap price	Calculated metal value[2]	Quoted scrap price	Calculated metal value[2]
INCONEL alloy 718	Wrought nickel- and cobalt-base	2.50	2.72	5.98	3.26
WASPALOY.........	..............do................	5.50	5.54	8.50	6.35
INCONEL alloy 600	..............do................	1.75	1.61	2.76	2.34
Alloy 713C.......	Investment cast nickel- and cobalt-base.	2.75	2.63	5.04	3.35
B-1900+Hf........	..............do................	5.00	8.57	9.98	9.96

[1]This material was classed as vacuum grade by the scrap dealer.
[2]Based on producer prices for the contained elements as pure metals or master alloys.

Scrap Generation

The survey revealed three sources of alloy scrap generation. Home and prompt industrial scrap is generated by alloy producers and users during the raw material melting to primary production phase and the primary product to finished product phase of the production cycle. Scrap from both of these sources is generated relatively soon (less than 1 year) after the raw material melting operation. This scrap is assumed to be available for recycling in the same production year. Therefore, the quantity of available home and prompt industrial scrap can be calculated from production figures. Obsolete scrap, on the other hand, is generated long after finished product manufacturing. This form of scrap is the result of parts and equipment replacement and service wastage. Obsolescence may occur any time after manufacture and will depend on the design lifetime of the part, maintenance schedules, and the nature of the service. For the purpose of this study, based on responses to our survey, life cycles of 5 years for investment cast and hardfacing cast nickel- and cobalt-base alloys and 10 years for the other classes of alloys covered by this study were estimated.

The survey information and the experience of the International Nickel Co. with industry practices made it possible to estimate the proportions of the various forms of scrap (solids, turnings, grindings, skulls, spills, slags, dusts, scales, wastes) generated from each source. The quantity and form of home scrap generated in 1976 are given in table 15. This same information is given in table 16 for prompt industrial scrap. Note that these data were derived from estimated production figures and efficiencies and estimates as to the form and relative proportions of scrap generated thereby.

Table 17 shows the quantity and form of obsolete scrap which will be available, in the future, when finished products produced in 1976 from the chromium-containing alloys covered in this study are removed from service. The quantity of obsolete scrap available for use in 1976 was calculated using historical primary production data (fig. 2-3) as the base. Linear regression analyses were performed to determine the average annual primary production for 1958-78. It was assumed that the rate of obsolescence has a statistically normal distribution based on the average service life. Consequently, the average quantity of finished product produced in the year corresponding to start of the product life cycle was used to estimate the quantity of currently available obsolete scrap. These quantities are also given in table 17.

Note that the data used in subsequent sections on scrap utilization in 1976 are for currently available obsolete scrap.

TABLE 15. - Quantity of home scrap generated in 1976, by scrap form and alloy class

(million pounds)

Alloy class	Solids	Turnings	Grindings	Mixed[1]	Waste
Investment cast nickel- and cobalt-base.	2.4	0	0.8	1.0	1.7
Hardfacing cast nickel- and cobalt-base.	.8	0	.4	.4	.6
Wrought nickel- and cobalt-base.........	79.2	5.4	2.7	1.0	1.7
Wrought nickel-iron-base...............	40.4	2.8	.7	.7	1.4
Heat-resistant alloy castings...........	40.0	1.0	1.0	6.1	1.0
Corrosion-resistant alloy castings......	103.3	2.3	2.3	14.1	2.3
Total[2]...........................	266.1	11.5	7.8	23.3	8.7

[1]Mixed melt shop scrap.
[2]Grand total: 317.4 million pounds.

TABLE 16. - Quantity of prompt industrial scrap generated in 1976, by scrap form and alloy class

(Million pounds)

Alloy class	Solids	Turnings	Grindings	Waste
Investment cast nickel- and cobalt-base.........	11.3	0.7	1.6	0.4
Hardfacing cast nickel- and cobalt-base.........	0	1.5	1.5	.3
Wrought nickel- and cobalt-base.................	12.6	18.9	7.2	2.7
Wrought nickel-iron-base.......................	6.4	9.7	3.7	1.4
Heat-resistant alloy castings..................	0	1.0	0	0
Corrosion-resistant alloy castings.............	0	2.3	0	0
Total[1].................................	30.3	34.1	14.0	4.8

[1]Grand total: 83.2 million pounds.

TABLE 17. - Quantity of obsolete scrap represented by finished product produced in 1976 and obsolete scrap available in 1976, by scrap form and alloy class

(Million pounds)

Alloy class	Future obsolete scrap[1]			Current obsolete scrap[2]		
	Solids	Grindings	Waste	Solids	Grindings	Waste
Investment cast nickel- and cobalt-base	8.4	0	0.9	7.6	0	0.8
Hardfacing cast nickel- and cobalt-base	2.4	0	2.4	2.2	0	2.1
Wrought nickel- and cobalt-base........	42.3	2.7	3.6	33.5	2.1	2.8
Wrought nickel-iron-base...............	21.6	1.4	1.8	17.1	1.1	1.5
Heat-resistant alloy castings..........	44.0	3.1	5.1	35.3	2.5	4.1
Corrosion-resistant alloy castings.....	77.4	7.0	23.5	48.5	4.4	14.7
Total[3].........................	196.1	14.2	37.3	144.2	10.1	26.0

[1]Represents scrap that will occur when finished products produced in 1976 are removed from service through repair, service wastage, or dismantling.
[2]Represents scrap available for use in 1976 derived from earlier years' production.
[3]Grand totals: 247.6 million pounds of future obsolete scrap and 180.3 million pounds of current obsolete scrap.

Scrap Export

Data on exports and imports of nickel waste and nickel alloy in 1965-78 were available from the Bureau of Mines (10) and are given in table 18. Some of the material included in this compilation is not included in the alloy classes covered by the current study; however, there is a large degree of overlap. Thus, these statistics serve as a useful cross-check on the results of the present study regarding alloy scrap exports.

TABLE 18. - Quantity of nickel waste and scrap exported and imported annually, 1965-78 (10)

(Million pounds)

Year	Exports	Imports	Net export
1965	13.4	4.6	8.8
1966	11.7	3.7	8.0
1967	27.8	4.4	23.4
1968	30.5	7.8	22.7
1969	34.2	6.4	27.8
1970	17.7	5.2	12.5
1971	11.2	2.7	8.5
1972	14.9	4.6	10.3
1973	12.5	5.3	7.2
1974	12.5	7.4	5.1
1975	16.3	4.7	11.6
1976	31.9	4.7	27.2
1977	16.8	6.4	10.4
1978	9.3	7.4	1.9
Average	18.6	5.4	13.2

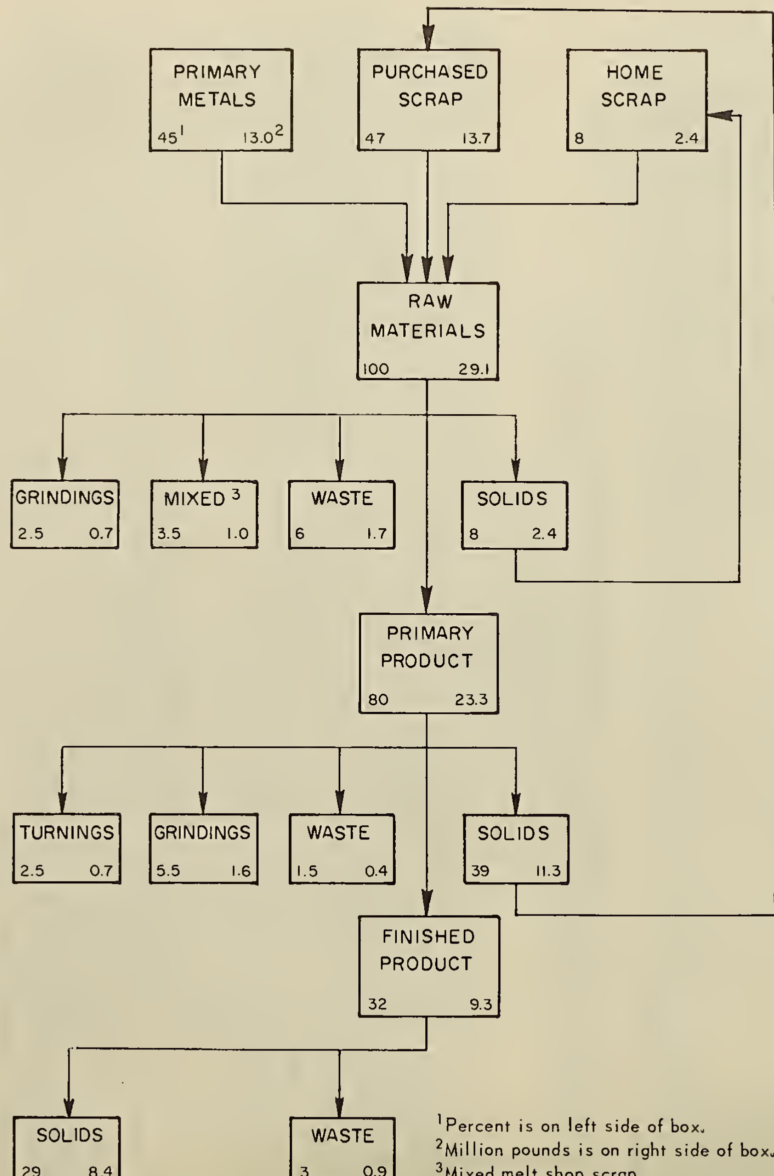
DISCUSSION

Materials Balance

The data on primary and finished product production, distribution of raw materials for melting, and types of scrap generated and utilized for the U.S. alloy producing and using industries covered in this study are presented as materials balance flow charts in figures 4 through 9. These figures show the form of material and scrap and its flow from the raw material melting stage through primary and finished product production to component obsolescence. Figure 10 shows an overall weighted average material balance flow chart for the industries covered in this study.

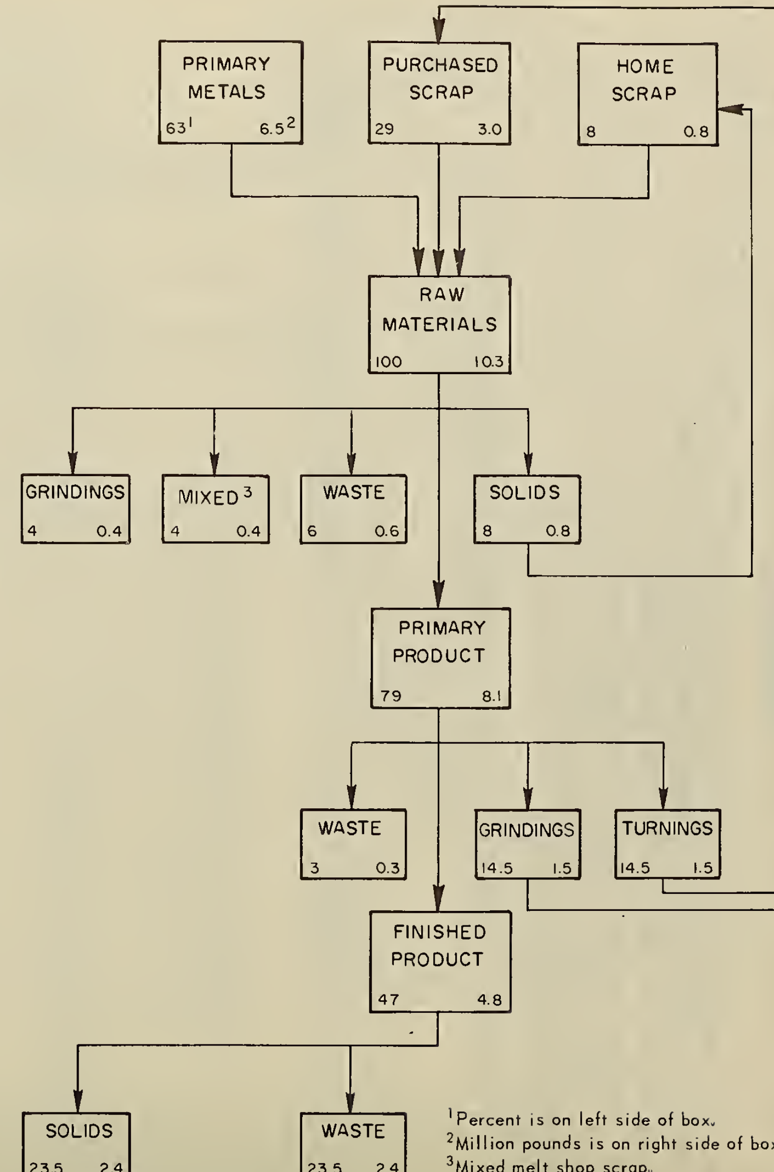
Use Patterns of the Alloy-Producing Industry

The alloy-producing industry use patterns shown in figures 4 through 10 have been in existence for at least the past 10 years. This study revealed no significant evidence that these use patterns will change in the near future. These alloy producers favor the use of the maximum amount of home scrap (43 percent) of the "same alloy" composition supplemented with purchased scrap



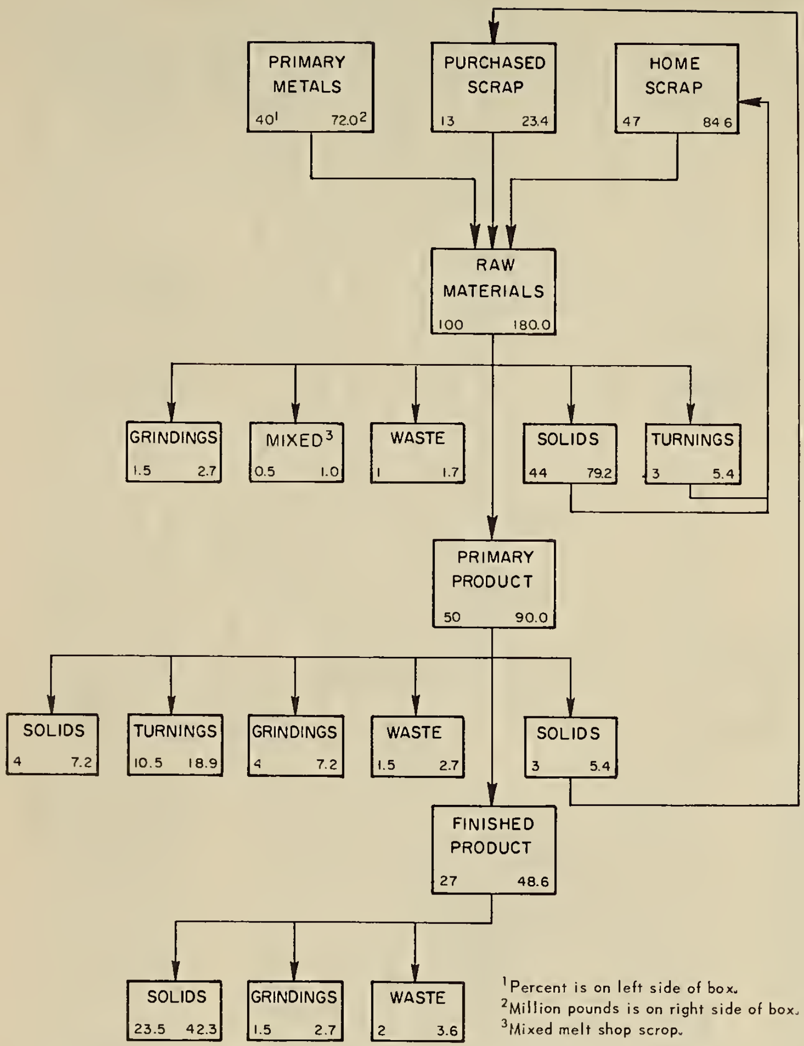
[1]Percent is on left side of box.
[2]Million pounds is on right side of box.
[3]Mixed melt shop scrap.

FIGURE 4. - Investment cast nickel- and cobalt-base alloys materials flow circuit.



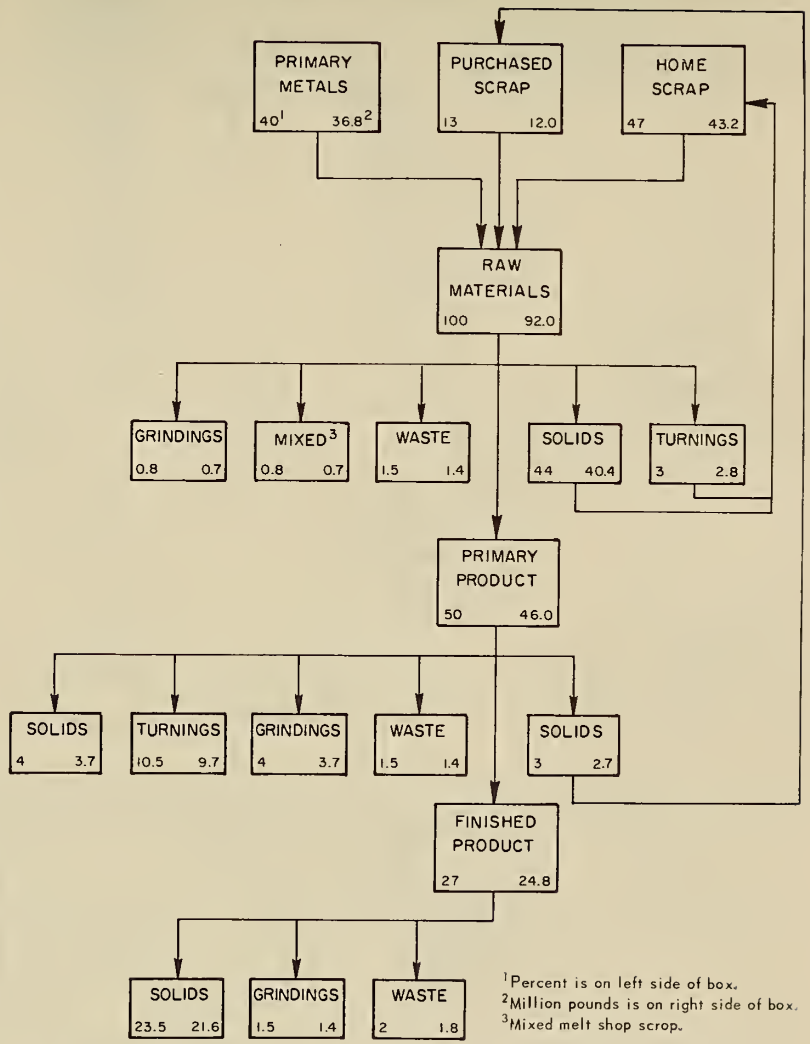
[1]Percent is on left side of box.
[2]Million pounds is on right side of box.
[3]Mixed melt shop scrap.

FIGURE 5. - Hardfacing cast nickel- and cobalt-base alloys materials flow circuit.



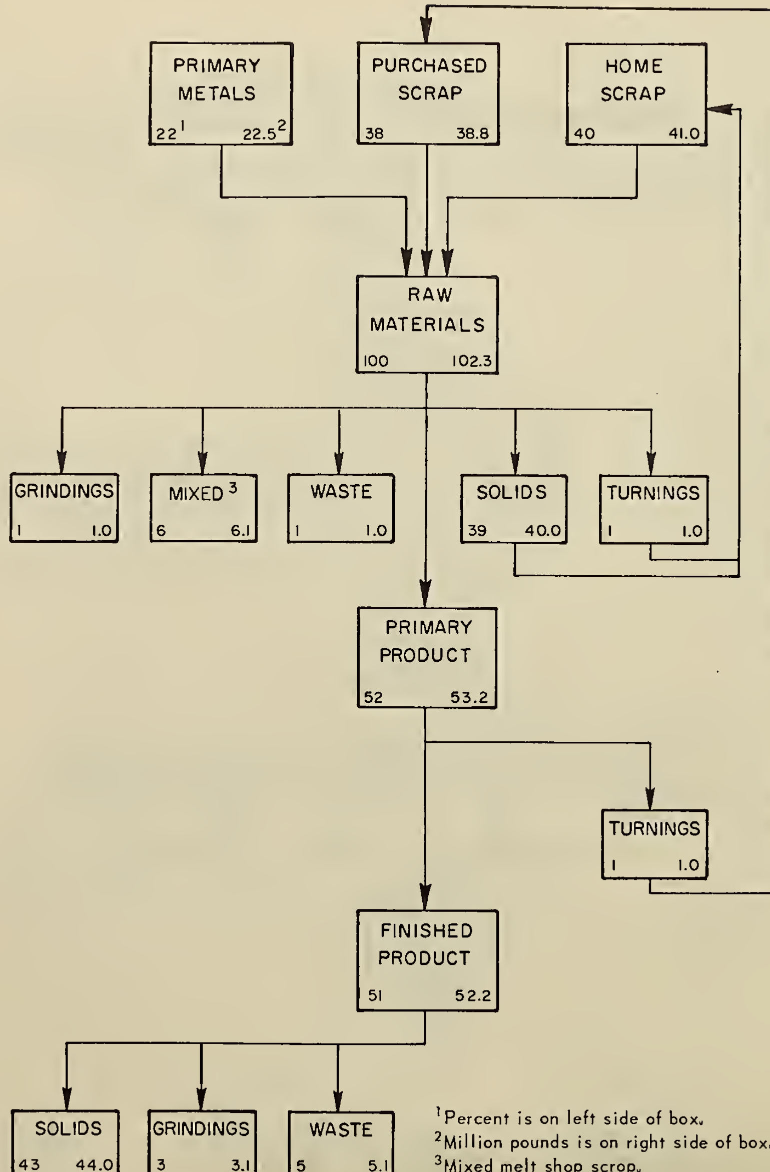
[1]Percent is on left side of box.
[2]Million pounds is on right side of box.
[3]Mixed melt shop scrap.

FIGURE 6. - Wrought nickel- and cobalt-base alloys materials flow circuit.



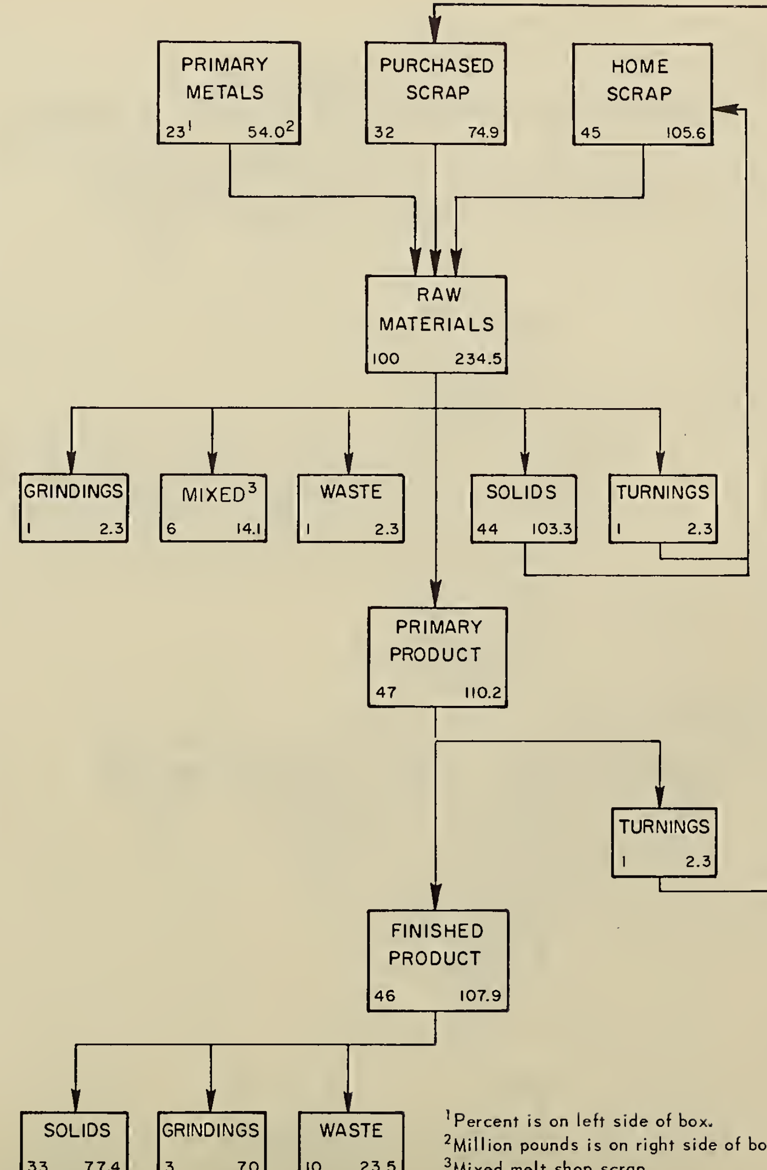
[1]Percent is on left side of box.
[2]Million pounds is on right side of box.
[3]Mixed melt shop scrap.

FIGURE 7. - Wrought nickel-iron-base alloys materials flow circuit.



[1]Percent is on left side of box.
[2]Million pounds is on right side of box.
[3]Mixed melt shop scrop.

FIGURE 8. - Heat-resistant alloy castings materials flow circuit.



[1]Percent is on left side of box.
[2]Million pounds is on right side of box.
[3]Mixed melt shop scrap.

FIGURE 9. - Corrosion-resistant alloy castings materials flow circuit.

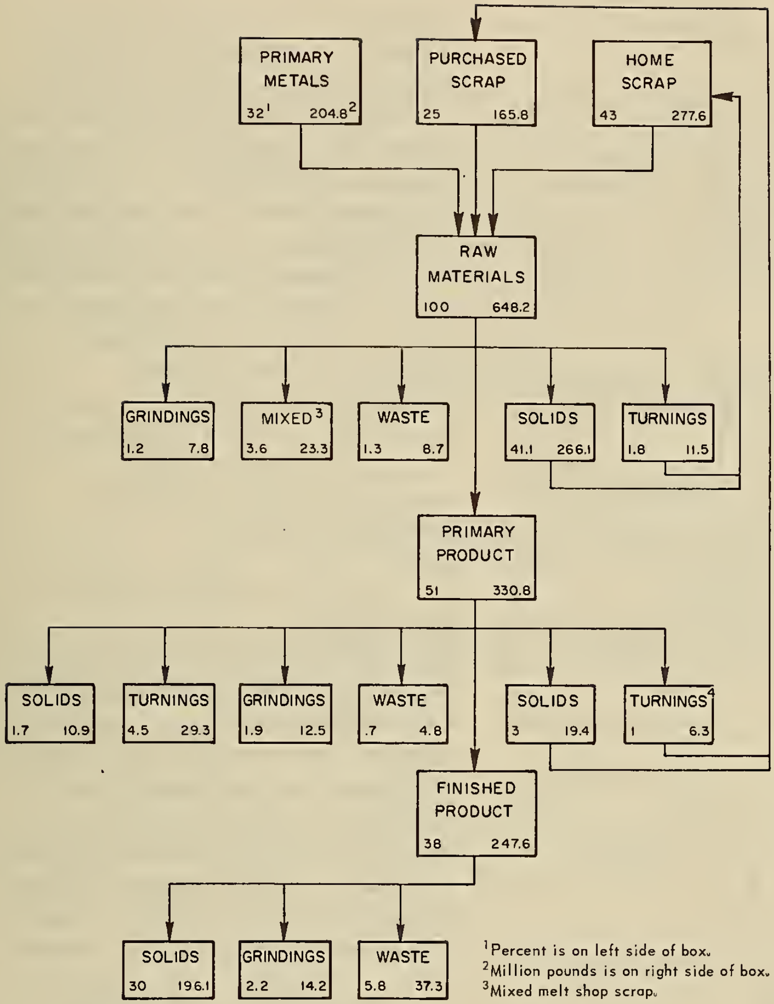


FIGURE 10. - Overall materials flow circuit.

(25 percent) of the same alloy, if possible, or alloy class. This is done primarily for the sake of economy and materials availability. Because of its intrinsic metal value and ready availability, home scrap is equal to primary metal as a melt stock. Under normal economic conditions, purchased scrap is priced at about 80 percent of the primary metals price and has comparable availability. This may not be true for complex alloys produced in small quantity (those in the other category). Such alloys will require more primary metal because some alloy scrap is less available. On the whole, however, alloy producers use all their suitable home scrap and as much purchased scrap as is allowed by metallurgical considerations.

Use of a substantial quantity (32 percent, or about 200 million pounds) of primary metals in the raw material charge is dictated primarily by metallurgical considerations. In the cast and wrought nickel- and cobalt-base alloy-producing industries, larger percentages of primary metals are used in the raw materials charge. The main reason for this is to minimize the pickup of iron and other "deleterious trace elements," such as lead and tin, small quantities of which are harmful to high-temperature properties. For example, in investment cast nickel- and cobalt-base alloys, about 45 percent of the raw materials charge is primary metals, as compared to about 22 percent for heat-resistant alloy castings. About 63 percent of the charge is primary metal for the cast nickel- and cobalt-base alloys used for hardfacing owing to unavailability of scrap of suitable composition.

In developing the model, it was assumed that scrap not recycled within an alloy class is downgraded or exported. This was done to simplify the calculations and because it was felt that the results would not be significantly altered. In some cases, this assumption is true; that is, cast nickel-base alloys cannot be readily used in the other alloy classes because of the

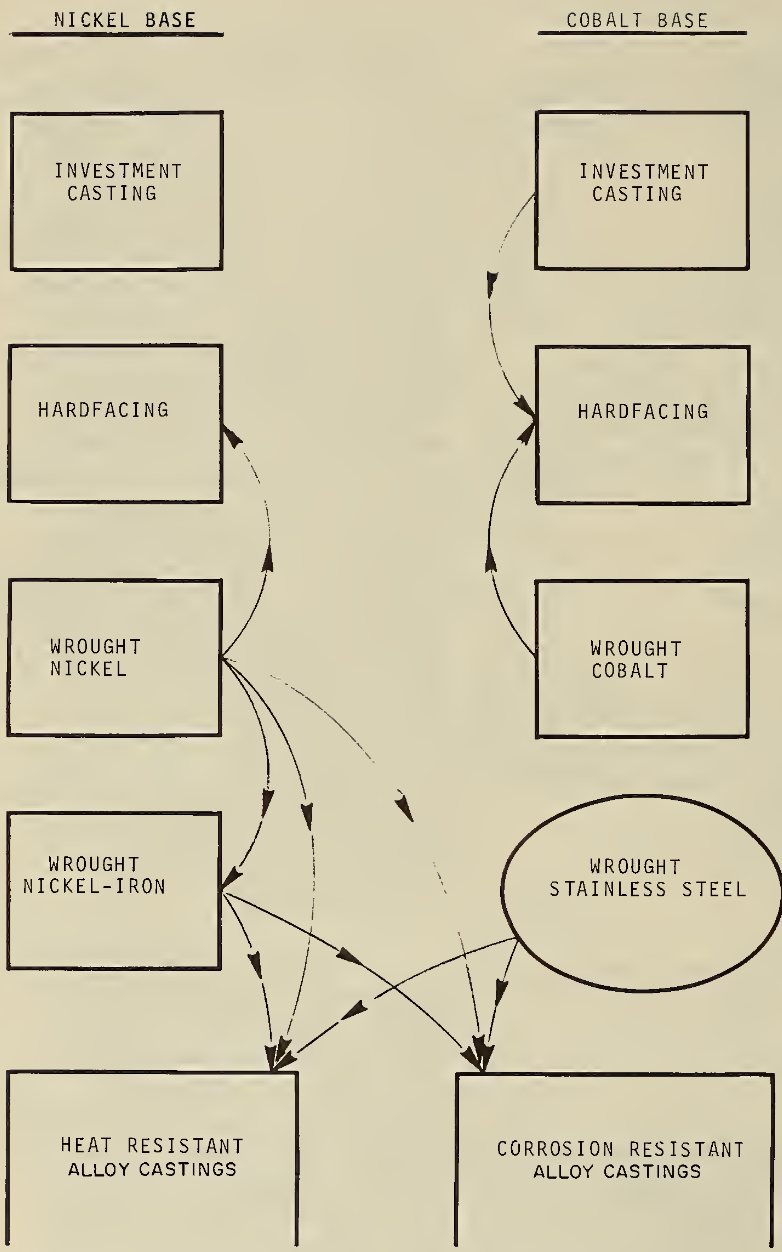


FIGURE 11. - Schematic diagram showing interclass scrap flow.

presence of undesirable elements. A schematic diagram indicating a likely pattern of interclass scrap flow is shown in figure 11. This diagram indicates a net flow of scrap into the hardfacing cast nickel- and cobalt-base alloy categories and a probable inflow of stainless steel scrap for melting heat- and corrosion-resistant castings. Quantification of this hypothetical flow pattern will require a more detailed industry survey.

It is unlikely that the superalloy and heat- and corrosion-resistant alloy casting industries will significantly increase the average percentage of scrap utilized in raw material charges. A major breakthrough in alloy melting and refining technology will be needed to allow recycling of additional high-alloy scrap.

There is a trend in these industries for the alloy producers to buy prompt industrial and obsolete scrap directly from fabricators, manufacturers, and end users rather than obtaining this scrap indirectly through scrap dealers. Several companies have recently set up scrap reprocessing facilities to improve their utilization of scrap. Others are investigating processes to increase the efficiency of recycling home scrap material presently unsuitable for direct remelting. The trend is taking place because producers wish to develop more assured supplies of raw materials in time of severe primary metals shortage. While these new practices change the flow pattern of the purchased scrap component of the raw materials charge, they will not affect the relative quantity used.

Scrap Utilization

The disposition of the scrap generated in 1976 by the industries covered in this study was estimated from the general assessments given in response to inquiries or key assumptions where information was not available. Four categories of scrap utilization were defined: "remelted," "lost," "downgraded," and "exported." The quantities of scrap distributed in these four categories are given in tables 19-22. Each category is discussed separately below. For convenience in comparing all four scrap utilization categories, this information has been summarized in table 23.

TABLE 19. - Scrap requirements for remelting, by alloy class and scrap form and origin

(Million pounds)

Alloy class	Scrap of same alloy class					Scrap of other alloy classes	Scrap totals
	Home		Prompt industrial		Obsolete solids		
	Solids	Turnings	Solids	Turnings[1]			
Investment cast nickel- and cobalt-base...............	2.4	0	11.3	0	2.4	0	16.1
Hardfacing cast nickel- and cobalt-base...............	0.8	0	0	3.0	0	0	3.8
Wrought nickel- and cobalt-base........	79.2	5.4	5.4	0	18.0	0	108.0
Wrought nickel-iron-base...............	40.4	2.8	2.7	0	9.3	0	55.2
Heat-resistant alloy castings..........	40.0	1.0	0	1.0	35.3	[2]2.5	79.8
Corrosion-resistant alloy castings.....	103.3	2.3	0	2.3	48.5	[3]24.1	180.5
Total[4].........	266.1	11.5	19.4	6.3	113.5	26.6	443.4

[1]Includes grindings.
[2]Requirement for average 24 percent chromium-20.5 percent nickel-balance iron alloy may be made up using wrought stainless steel and/or wrought nickel- and nickel-iron-base alloy scrap.
[3]Requirement for average 18.6 percent chromium-8.9 percent nickel-balance iron alloy may be made up using wrought stainless steel scrap.
[4]Grand total: 443.4 million pounds.

Remelted

Table 19 shows the sources of scrap for remelting by alloy class and scrap form. This information was derived from the scrap source data in tables 15 through 17 and the information on scrap use preferences received from previous inquiries. Note that in all alloy classes, except hardfacing nickel- and cobalt-base alloys, it was concluded that solid scrap is utilized to fill out the necessary scrap segment of the melt charge. In the case of

the hardfacing nickel- and cobalt-base alloy industry, there is a lack of suitable solid scrap and available turnings and grindings are therefore recycled as scrap feedstock. As noted previously, some solid scrap from other cobalt-base alloy classes may be used in the raw materials charge.

TABLE 20. - Sources of lost scrap, by alloy class and scrap origin

(Million pounds of contained metal)

Alloy class	Home	Prompt industrial	Obsolete[1]	Total	Contained chromium[2]
Investment cast nickel- and cobalt-base	1.7	0.4	0.8	2.9	0.4
Hardfacing cast nickel- and cobalt-base	.6	.3	2.1	3.0	.7
Wrought nickel- and cobalt-base........	1.7	2.7	2.8	7.2	1.3
Wrought nickel-iron-base...............	1.4	1.4	1.5	4.3	.6
Heat-resistant alloy castings..........	1.0	0	4.1	5.1	1.2
Corrosion-resistant alloy castings.....	2.3	0	14.7	17.0	3.2
Total..........................	8.7	4.8	26.0	39.5	7.4

[1]Represents current obsolete scrap available for use in 1976 derived from earlier years' production.
[2]Calculated from average compositions of table 25.

TABLE 21. - Sources of scrap downgraded, by alloy class and scrap form and origin

(Million pounds)

Alloy class	Home		Prompt industrial			Obsolete[2]		Total	Contained chromium[3]
	Grindings	Mixed[1]	Solids	Turnings	Grindings	Solids	Grindings		
Investment cast nickel- and cobalt-base.......	0.7	1.0	0	18.9	1.6	2.6	0	6.6	0.9
Hardfacing cast nickel- and cobalt-base.......	.4	.4	0	0	0	2.2	0	3.0	.7
Wrought nickel- and cobalt-base.......	2.7	1.0	3.6	18.9	7.2	7.8	2.1	43.3	7.9
Wrought nickel-iron-base.........	0.7	0.7	1.8	9.7	3.7	3.9	1.1	21.6	3.2
Heat-resistant alloy castings....	1.0	6.1	0	0	0	0	2.5	9.6	2.3
Corrosion-resistant alloy castings....	2.3	14.1	0	0	0	0	4.4	20.8	3.9
Total[4]........	7.8	23.3	5.4	29.3	12.5	16.5	10.1		

[1]Represents current obsolete scrap available for use in 1976 derived from earlier years.
[2]Mixed melt shop scrap.
[3]Calculated from average compositions of table 25.
[4]Grand total: 104.9 million pounds of scrap containing 18.9 million tons of chromium.

Material Losses

Dust, scale, and slag are generated during the production of the primary product. This material is contaminated and unsuitable for presently known recycling

technology. Table 20 shows the amount of this material, along with estimates of the amount of unsuitable scrap generated during the production of finished products (pickle sludges, electrochemical and electrodischarge machining wastes, and scales) and the amount of service wastage. The 40 million pounds of material lost in this manner in 1976 represents 6.1 percent of the alloy raw materials melted in that year. Included in this figure is 1 to 2 percent of solid scrap that is inadvertently lost during the scrap reclamation processes owing to misclassification.

TABLE 22. - Sources of solid scrap exported, by alloy class and scrap form and origin

(Million pounds)

Alloy class	Prompt industrial solids	Obsolete[1] solids	Total	Contained chromium
Investment cast nickel- and cobalt-base	0	2.6	2.6	0.3
Hardfacing cast nickel- and cobalt-base	0	0	0	0
Wrought nickel- and cobalt-base........	3.6	7.7	11.3	2.1
Wrought nickel-iron-base...............	1.9	3.9	5.8	0.9
Heat-resistant alloy castings..........	0	0	0	0
Corrosion-resistant alloy castings.....	0	0	0	0
Total[2]............................	5.5	14.2		

[1]Represents current obsolete scrap available for use in 1976 derived from earlier years.

[2]Grand total: 19.7 million pounds of scrap containing 3.3 million tons of chromium.

Downgraded

This study revealed that a large quantity of superalloy scrap is underutilized, in the sense that it is downgraded. This includes both solids and turnings, which may be of high quality, and grindings and mixed melt shop scrap (skulls and spills), which are of lower quality. Downgrading is defined as reuse of alloy scrap as a raw material feedstock or reprocessed feedstock for remelting in an alloy class that has less stringent quality requirements. Scrap flow within the six alloy classes surveyed was not included in this analysis. The quantity of scrap that is currently downgraded is given by alloy class and scrap form in table 21. This information was derived from tables 15, 16, and 17 using the assumptions discussed earlier. For instance, it was assumed that all of the turnings, grindings, and mixed melt shop scrap not being remelted are downgraded. In addition, it was assumed that half of the available solid scrap not being remelted or lost is downgraded. Responses to the survey supported these assumptions. Note that through the use of these assumptions, a simplified view of an extremely complex industry is presented. Therefore, while there are currently efforts underway to develop technology to recycle certain grindings, sludges, and so forth, the total of material recycled in this manner is currently small and will be neglected for the purpose of this study.

TABLE 23. - Scrap recycling, by alloy class and scrap disposition

(Million pounds)

Alloy class	Remelted			Downgraded			Lost			Exported		
	Home	Prompt industrial	Obsolete[1]	Home	Prompt industrial	Obsolete[1]	Home	Prompt industrial	Obsolete[1]	Home	Prompt industrial	Obsolete[1]
Investment cast nickel- and cobalt-base	2.4	11.3	2.4	1.7	2.3	2.6	1.7	0.4	0.8	0	0	2.6
Hardfacing cast nickel- and cobalt-base	.8	3.0	0	.8	0	2.2	.6	.3	2.1	0	0	0
Wrought nickel- and cobalt-base	84.6	5.4	18.0	3.7	29.7	9.9	1.7	2.7	2.8	0	3.6	7.7
Wrought nickel-iron-base	43.2	2.7	9.3	1.4	15.2	5.0	1.4	1.4	1.5	0	1.9	3.9
Heat-resistant alloy castings	41.0	1.0	35.3	7.1	0	2.5	1.0	0	4.1	0	0	0
Corrosion-resistant alloy castings	105.6	2.3	48.5	16.4	0	4.4	2.3	0	14.7	0	0	0
Total[2]	277.6	25.7	113.5	31.1	47.2	26.6	8.7	4.8	26.0	0	5.5	14.2

[1]Represents current obsolete scrap available for use in 1976 derived from earlier years' production.
[2]Grand total: 580.9 million pounds (416.8 remelted, 104.9 downgraded, 39.5 lost, and 19.7 exported).

The 105 million pounds of chromium containing nickel-, cobalt-, and nickel-iron-base alloy and heat- and corrosion-resistant scrap downgraded in 1976 represents about 16 percent of the raw materials melted in that year. This scrap contained 18.9 million pounds of chromium.

Approximately one-half of this scrap (54 million pounds) occurs as grindings and mixed melt shop scrap and is unsuitable for recycling to the same alloy class using current recycling technology. This material is now reprocessed by "secondary metal" refiners who experience a relatively low recovery rate because of the processes required to remove impurities. The refined ingot is used as a nickel-rich feedstock for the stainless steel, cast iron, or alloy steel industries. An undefined amount (perhaps as much as one-half) of the chromium, plus other valuable elements (molybdenum, tungsten, etc.), is lost by oxidation during the remelting cycle at the refinery. Cobalt is retained as a minor constituent and is added to stainless, cast iron, or alloy steels as an unintentional alloying element.

The remaining 51 million pounds of downgraded alloy scrap occurs as solids and turnings which are suitable for direct charging to the melting furnace in the stainless steel, cast iron, and alloy steel industries. In this case, most of the chromium is recovered but its value is essentially equivalent to that of low-carbon ferrochromium, although it may have originated as expensive, high-purity chromium metal.

Exported

The study showed that many individuals believed that a significant quantity of chromium-containing alloy scrap is being exported. This view was confirmed by several scrap dealers and by an industry consultant. In 1976, based on information reported by the Bureau of Mines (10), 31.9 million pounds of nickel wastes and nickel alloy scrap were exported from the United States. The very broad export classification used includes most of the alloy classes covered in this study. The information supports the view that a significant quantity of chromium-containing scrap is exported.

In the absence of specific information, it was assumed that about one-half of the available prompt industrial and obsolete solid alloy scrap is exported. Table 22 shows that about 20 million pounds of chromium-containing alloy scrap was exported in 1976. This quantity is consistent with the Bureau of Mines data. It represents approximately 3 percent of the raw material melted for these alloy classes in that year.

The quality of scrap exported is high and thus represents a significant depletion of potential chromium reserves for the domestic metals industries. On the other hand, the commercial value of scrap (selling price) is presumed to be higher in the export market than the value as a domestic steel charge.

An additional contributing factor to the flow of chromium-containing alloy scrap from the United States is the construction of plants and machinery for export. Unless the direction of scrap flow reverses--currently nickel-containing scrap exports average 3½ times greater than imports (10)--it is

unlikely that the obsolete scrap, derived from dismantled petroleum, chemical processing, and power-generating plants, will re-enter the United States. Such applications involve sizable quantities of alloy castings and wrought nickel-, cobalt- and nickel-iron-base alloys. A quantitative assessment of material in this category was considered to be outside the scope of this study.

The investment cast nickel- and cobalt-base alloys used in the manufacture of exported commercial and military aircraft gas turbine engines were found to be recovered in the United States. These engines are currently repaired and ultimately scrapped at major repair facilities in the United States.

Efficiency of Recycling

From the data for raw materials melted given in table 9 and the data for quantity of scrap remelted given in table 19, it is possible to calculate the current scrap recycling efficiency for the alloy industries covered in this study by alloy class. Recycling efficiency, expressed in percent of the melt charge, is presented in table 24. As noted earlier, the present level of scrap recycling efficiency is dictated primarily by metallurgical considerations such as trace element control and physical and mechanical property specifications imposed by the alloy users. Therefore, it is concluded that the alloy producers are making maximum use of available high-quality chromium-containing alloy scrap within these materials specifications.

TABLE 24. - Calculated recycling efficiency for the six classes of alloy

Alloy class	Current scrap recycling efficiency,[1] percent	Potential scrap recycling efficiency,[2] percent
Investment cast nickel- and cobalt-base.......	55	76
Hardfacing cast nickel- and cobalt-base.......	37	58
Wrought nickel- and cobalt-base...............	60	83
Wrought nickel-iron-base......................	60	83
Heat-resistant alloy castings.................	78	78
Corrosion-resistant alloy castings............	77	77

[1]Expressed as percent of all available scrap.
[2]Using all available solids and turnings (currently downgraded and/or exported).

If melting and refining technology were developed or materials specifications were relaxed to allow complete recycling of all available high-quality chromium-containing alloy scrap (solids and turnings), the recycling efficiencies could be increased for the more highly alloyed materials, as shown in the second column of table 24. More scrap would be used if it were less expensive and more readily available than primary metals. While this development would not eliminate the requirement for primary raw materials, the quantities required would be reduced.

Scrap Price Considerations

Metal scrap prices have a history of volatility because they reflect a sensitive free market response to supply and demand for raw materials. In times of ready availability of primary metals, the free market prices for both scrap and primary metals are lower than the quoted producer price. When demand for primary metals exceeds supply due to increase in demand or decrease in supply, the free market price exceeds the producer price. For relatively simple alloys, the free market price of scrap is about half of that of the contained pure metals. This varies somewhat among different alloys for a number of metallurgical and commercial reasons, but the ratio has been consistent for approximately the last 20 years. Scrap price is also dependent on the grade or quality. Three categories in common use for nickel alloys are "vacuum melting," "air melting," and "refinery" grades. The prices for these grades are approximately 80 percent, 50 percent, and 35 percent of the primary metal prices. The factors that determine scrap grade are degree of identification, cleanliness, and size.

The overall situation for scrap prices is more complex for the multicomponent alloys considered in this study. Because primary metal sources of any of the constituents may be subject to restricted supply situation at any given time, cost fluctuations due to restricted supply may be superimposed on fluctuations due to variation in demand from the general economy. At certain times, the free market price of a single element can have a disproportionate effect on the price of alloy scrap. These two factors have influenced the price of chromium-containing alloy scrap in recent years. As mentioned earlier, 1976 was a period of relatively low demand and general availability of primary metals. Scrap prices were generally lower than producer prices of the contained primary metal values. This situation prevailed as recently as February 1979 (table 14). In contrast, the scrap prices quoted for May 1979 were 10 to 40 percent higher than producer prices of contained primary metals. This is due to three factors: increased alloy production, recent shortages of some forms of nickel and molybdenum, and very severe shortage of cobalt. The average producer price for cobalt in 1976 was $5.58 per pound, the May 1979 producer price was $25, and the May 1979 free market price was $37.50. The quotes for nickel alloy scrap in 1979 include a surcharge for cobalt at the current free market price. Based on historical evidence, it is likely that the free market price for both primary metal and scrap will drop sharply when more cobalt becomes available through increased production of primary metal and reduced demand. The present experience, however, provides an excellent example of how a minor scrap component can temporarily control price.

Quantity of Chromium Required for Melting

The estimates of quantity of alloy produced by the superalloy and heat- and corrosion-resistant alloy casting industries, given in tables 2 through 7, and the specific alloy compositions shown in appendix A were used to calculate weighted average compositions for each alloy class (table 25). Only the major elements, chromium, nickel, cobalt, and iron, are identified in this table, since these elements were of primary interest to the present study.

TABLE 25. - Calculated weighted average composition, by alloy class

Alloy class	Composition, weight-percent				
	Cr	Ni	Co	Fe	Others
Investment cast nickel- and cobalt-base...	13.3	63.6	7.4	1.1	14.6
Hardfacing cast nickel- and cobalt-base...	24.3	8.0	54.9	.7	12.0
Wrought nickel- and cobalt-base..........	18.2	62.5	4.8	7.0	7.5
Wrought nickel-iron-base.................	15.0	34.1	3.5	42.1	5.3
Heat-resistant alloy castings............	24.0	20.5	0	55.5	0
Corrosion-resistant alloy castings........	18.6	8.9	0	72.5	0

The technique used to obtain the weighted average compositions involved (1) multiplying the estimated weight of primary product for each alloy within a particular alloy class by the composition of that alloy, (2) summing the pounds of individual elements thus derived, and (3) dividing those sums by the total weight of primary product in that class. It was assumed that within any given alloy class, the primary production efficiency was about equal for all alloys.

The quantity of chromium contained in raw materials in 1976 was calculated by multiplying the melt charge requirements shown in table 12 by the percentage of chromium in the average composition in table 25. This calculation assumes that only "same alloy" scrap is used in the melt charge. The derived chromium content figures are given in table 26.

TABLE 26. - Chromium content of melt charge components, by alloy class

(Million pounds)

Alloy class	Primary metal	Home scrap	Purchased scrap	Total
Investment cast nickel- and cobalt-base..	1.7	0.3	1.8	3.8
Hardfacing cast nickel- and cobalt-base..	1.6	.2	.7	2.5
Wrought nickel- and cobalt-base..........	13.1	15.4	4.3	32.8
Wrought nickel-iron-base.................	5.5	6.5	1.8	13.8
Heat-resistant alloy castings............	5.4	9.8	9.3	24.5
Corrosion-resistant alloy castings.......	10.0	19.6	13.9	43.5
Total..............................	37.3	51.8	31.8	120.9

Table 27 shows the quantity of chromium lost from the domestic alloy production circuit in 1976. These data are derived from the information in tables 20-22 and 25. Note that the quantity of primary chromium required for the melt charge (table 26) is 7.7 million pounds greater than the amount lost from the circuit (table 27). This is the quantity of chromium required to account for market growth over the period of obsolete scrap generation.

In 1976 37.3 million pounds of new primary chromium was required for melting by the superalloy and heat- and corrosion-resistant casting industries. While this figure could be reduced somewhat by improved recycling efficiency, most of this chromium requirement is necessary to replace scrap that is unsuitable or unavailable for recycling or to account for market growth.

For example, if all available solids and turnings scrap were recycled, the primary chromium requirement could be reduced to 25 million pounds. Subtracting the chromium required for market growth (7.7 million pounds), about 17 million pounds of chromium metal was lost to these alloy-producing industries, because it was contained in poor-quality scrap (grindings, mixed melt shop scrap, service wastage) or lost high-quality scrap.

TABLE 27. - Chromium content of scrap not directly recycled in 1976

(Million pounds)

Alloy class	Scrap disposition			Total	Contained chromium
	Lost	Down-graded	Exported		
Investment cast nickel- and cobalt-base	2.9	6.6	2.6	12.1	1.6
Hardfacing cast nickel- and cobalt-base	3.0	3.0	0	6.0	1.5
Wrought nickel- and cobalt-base........	7.2	43.3	11.3	61.8	11.2
Wrought nickel-iron-base...............	4.3	21.6	5.8	31.7	4.8
Heat-resistant alloy castings..........	5.1	9.6	0	14.7	3.5
Corrosion-resistant alloy castings.....	17.1	20.8	0	37.8	7.0
Total............................	39.5	104.9	19.7	164.1	29.6

Relationship to Total U.S. Chromium Requirements

Having established the primary metals chromium requirements, it is possible to determine the quantities of the various forms of primary chromium required for the six alloy classifications. This was accomplished by estimating the requirements for pure chromium metal (aluminothermic and electrolytic), high-carbon ferrochromium, and low-carbon ferrochromium (including ferrochromium-silicon) for each alloy class. These estimates are given in table 28. Note that the requirement of 7.2 million pounds of pure chromium metal represents about 20 percent of the total primary metal chromium required by the industries described in this study.

The primary chromium metal requirements of these industries are compared with the total metallurgical requirements in the United States for 1976 in table 29. Total consumption of chromium by the alloy industries covered in this study was 7.7 percent of the total. However, these industries accounted for 95 percent of the consumption of the highest quality, most expensive forms of chromium.[7]

The trend in these industries over the past 5 years has been toward the use of more high-carbon ferrochromium at the expense of more costly low-carbon ferrochromium. This trend is associated with the advent of the argon-oxygen decarburization process for alloy production. This process is being used to produce a number of wrought nickel- and nickel-iron-base alloys, as well as cast heat- and corrosion-resistant alloys. However, alloys containing chromium-iron ratios greater than 2.5:1 will continue to require chromium metal.

[7]The chromium requirement was estimated from the production model of the industry. A representative of one of the two U.S. producers of chromium metal estimated that 90 percent, or 6.9 million pounds, was actually used in nickel alloys. The agreement is well within the assumed accuracy of the model.

TABLE 28. - Quantities of primary metal chromium used in the melt charge in 1976

Alloy class	Primary metal chromium used, million pounds	Chromium metal[1]		Chromium as high-carbon ferrochromium		Chromium as low-carbon ferrochromium	
		Percent[2]	Million pounds of chromium	Percent[2]	Million pounds of chromium	Percent[2]	Million pounds of chromium
Investment cast nickel- and cobalt-base..............	1.7	100	1.7	0	0	0	0
Hardfacing cast nickel- and cobalt-base..............	1.6	100	1.6	0	0	0	0
Wrought nickel- and cobalt-base..............	13.1	30	3.9	50	6.6	20	2.6
Wrought nickel-iron-base...	5.5			70	3.9	30	1.6
Heat-resistant alloy castings.................	5.4	0	0	60	3.2	40	2.2
Corrosion-resistant alloy castings................	10.02	0	0	60	6.0	40	4.0
Total................	37.3	NAp	7.2	NAp	19.7	NAp	10.4

NAp Not applicable.
[1]Electrolytic and aluminothermic chromium.
[2]Expressed as percent of primary metals chromium used.

TABLE 29. - Relation between primary chromium consumed for the six alloy classes and total primary chromium consumed for metallurgical applications in 1976

Form	Consumption of chromium for metallurgical applications during 1976 in the United States, million pounds[1]	Primary chromium consumed in all alloy classes, this study, million pounds	Percent of form used
Low-carbon ferrochromium and ferrochromium-silicon......	159.1	10.4	6.5
High-carbon ferrochromium...	319.0	19.7	6.2
Chromium metal.............	7.6	7.2	95.0
Total.................	485.7	37.3	[2]7.7

[1]Morning, J. L. Chromium. BuMines Minerals Yearbook 1976, v. 1, 1978, pp. 297-308.
[2]Percent of total U.S. chromium consumption used for the alloy classes covered in this study.

Past Trends in Alloy Production and Scrap Generation in the Superalloy and Heat- and Corrosion-Resistant Alloy Casting Industries, Projected to the Year 2000

The quantity of raw materials required for the six alloy classes as derived from various data sources for 1958-78 was shown previously in tables 8 and 9 and figures 2 and 3. A regression analysis of this data was performed to provide the curves shown. These curves show an average annual growth rate for heat- and corrosion-resistant high-alloy castings of 2 and 3.2 percent, respectively. Investment cast, hardfacing and wrought nickel- and cobalt-base alloys, and wrought nickel-iron-base alloys were assumed to grow at the same rate as nickel consumption for those alloy classes. As shown in figure 3, that is an annual growth rate of 2.1 percent per year.

These data show that the superalloy and heat- and corrosion-resistant alloy casting industries have experienced relatively low growth rates (less than 3 percent per year). These industries are also subject to severe cyclical fluctuations. Except for a strong demand by the "aerospace industry," which began late in 1977 and is expected to continue for 5 to 10 years, it is difficult to anticipate a change in the overall growth rate in these industries for the next 20 years. This is reflected in the dotted line projections in figures 2 and 3.

Major commercial events that could substantially increase demand for these alloys include extensive construction of coal conversion equipment, widespread adoption of the automotive gas turbine, a major military procurement program (gas-turbine-powered tanks), and adoption of nickel-base alloy tubing for sour oil or gas wells. Unless major breakthroughs occur, there is very little likelihood of significant replacement of chromium-containing alloys with materials such as ceramics or coated alloys, before the year 2000.

Research and development efforts are underway in the aerospace industry to provide improved melt-charge-to-finished-product yields. If these efforts are successful, the scrap generated will be substantially reduced. "Near net shape processing" using metal powders is one such approach. Producers of simple, wrought alloys are exploring "continuous casting" as a means for eliminating ingot hot tops and reducing wastage during hot working. Widespread use of this technology would reduce the availability of home scrap in the wrought nickel- cobalt- and nickel-iron-base alloy categories. This improvement in production efficiency would change the proportions of home and purchased scrap in the melt charge but would not necessarily increase scrap demand because of commensurate reduction in raw materials requirements.

Comments on Improving the Model and Continuing Surveillance of Field

The industries treated in this study are specialized, complex, and highly competitive. Consequently, it is difficult to obtain precise information on alloy production, melt charge make-up, primary and finished product yield, and scrap recycling practices. This report is based on a production model (figures 4 through 10) of these industries that was generated from data estimated to be reliable within ±20 percent.

A first step toward improving the model would be to conduct a more comprehensive survey of the chromium-containing-alloy production and scrap-generating industries. The largest gap in the present model occurs with respect to disposition of prompt industrial and obsolete scrap processed by the recyclers. It would be of considerable value if a trade association of the recyclers would collect and publish statistics on chromium-containing-alloy scrap.

The U.S. Department of Commerce and the U.S. Department of the Interior, Bureau of Mines, maintain up-to-date statistics on many categories of raw material consumption and alloy production. However, these statistics are not sufficiently detailed to provide adequate information on the chromium-containing-alloy industry. In view of the critical nature of this industry

to the U.S. manufacturing, transportation, energy conversion, and defense industries, it is clear that more comprehensive and specific data re required.

SUMMARY

A production model was developed for six classes of chromium-containing alloys, which included the cast and wrought nickel-, cobalt-, and nickel-iron-base alloys and heat- and corrosion-resistant casting alloys. Based on available information and a survey of alloy producers, finished product manufacturers, and users, information was gathered to determine a best estimate of production practices and quantity of products and scrap produced at each stage of production. The character and disposition of the scrap generated were determined. Calculations were then made to determine the quantities of the critical metals, chromium, nickel, and cobalt that are currently being lost from these alloy-producing industries through export, downgrading to lower alloy grades such as stainless steel, or loss to landfill disposal.

First, an accurate estimate was made of the quantity and average composition of primary production for 1976. This year was chosen because it was the latest year for which the most complete production data were available. In 1976, 330.8 million pounds of primary product was produced of the six alloy classes covered by this study. The quantities of alloying elements required to produce these alloys are summarized in table 30.

TABLE 30. - Quantity of contained elements in products and scrap in 1976

Source	Element, million pounds					
	Cr	Ni	Co	Fe	Others	Total
Raw material[1]	121.1	205.0	19.7	278.5	23.9	648.2
Primary metals	37.3	75.8	9.3	72.4	10.0	204.8
Primary product	61.6	108.1	12.1	135.5	13.6	330.8
Finished product	47.6	65.4	6.5	121.2	6.9	247.6
Remelted scrap[2]	78.6	126.6	10.4	187.4	13.8	416.8
Downgraded scrap	18.9	42.7	5.0	32.6	5.7	104.9
Lost scrap	7.5	10.6	2.4	17.5	1.5	39.5
Exported scrap	3.3	10.7	.9	3.3	1.5	19.7

[1]Includes primary metals, home scrap, and purchased scrap.
[2]Does not include 26.6 million pounds of scrap purchased from outside alloy classes.

Second, the alloy producers provided an estimate of their efficiency of production, which averaged 51 percent. From this and the quantity of primary product, it was possible to calculate that 648.2 million pounds of primary metals and purchased and home scrap were melted by the cast and wrought nickel-, cobalt-, and nickel-iron-base alloy and heat- and corrosion-resistant alloy casting producers in 1976. Further inquiry showed that the average relative mixture of raw materials for melting was 32 percent (204.8 million pounds) primary metals, 25 percent (165.8 million pounds) purchased scrap, and 43 percent (277.6 million pounds) home scrap. In addition, the alloy producers were asked to characterize the scrap material generated from the production cycle. The form and quantity of home scrap generated during the alloy

production cycle is shown in table 31, row 1. Disposition of home scrap is given in table 32, column 1.

TABLE 31. - Source, form, and quantity of scrap generated in 1976

(Million pounds)

Source	Solids	Turnings	Grindings	Mixed	Waste	Total
Home..................	266.1	11.5	7.8	23.3	8.7	317.4
Prompt industrial.....	30.3	34.1	14.0	0	4.8	83.2
Obsolete[1]............	144.2	0	10.1	0	26.0	180.3
Total............	440.6	45.6	31.9	23.3	39.5	580.9

[1]Obsolete scrap available in 1976 derived from previous years' production.

TABLE 32. - Scrap disposition by source and form in 1976

(Million pounds)

Disposition and form	Source			Total
	Home	Prompt industrial	Obsolete	
Remelted:[1]				
Solids...........................	266.1	[1]19.4	113.5	
Turnings.........................	11.5	4.8	0	416.9
Grindings........................	0	1.5	0	
Downgraded:				
Solids...........................	0	5.4	16.5	
Grindings........................	7.8	12.5	10.1	104.9
Mixed............................	23.3	0	0	
Lost (waste).....................	8.7	4.8	26.0	39.5
Exported (solids)................	0	5.5	14.2	19.7
Total........................	317.4	83.2	180.3	580.9

[1]Does not include 26.6 million pounds of solid scrap purchased from outside alloy classes.

Next, the finished product manufacturing cycle was examined. Through discussions with manufacturers and industry experts, it was determined that the overall average efficiency of utilization of primary product in the manufacture of finished products was about 75 percent (38 percent of the raw materials melted). Thus, of the 330.8 million pounds of primary product of the six alloy classes studies, it was estimated that 247.6 million pounds was contained in finished products (heat exchangers, gas turbine engines, chemical process equipment) in 1976 and that 83.2 million pounds of prompt industrial scrap was generated. The form and disposition of this prompt industrial scrap are given in tables 31 and 32.

Finally, discussions were held with end users, scrap dealers, and industry experts on the average life cycle and scrap practices for obsolete equipment. Based on these discussions, it was estimated that the average life cycle for

components made from cast nickel- and cobalt-base alloys was 5 years, compared with 10 years for products made from the remaining four alloy classes. An estimate was then made of the quantity of obsolete scrap that would occur in 1976 based on primary production data from previous years. The amount of service wastage and the character, quantity, and disposition of obsolete scrap generated when obsolete equipment was removed from service in 1976 were then estimated. Thus, 180.3 million pounds of obsolete scrap of cast and wrought nickel-, cobalt-, and nickel-iron-base alloys and heat- and corrosion-resistant cast alloys was generated in 1976. Note this is lower than the 247.6 million pounds of finished products manufactured from these alloys in that year. The form and disposition of obsolete scrap generated in 1976 are given in tables 31 and 32.

Regarding the overall recycling efficiency of these alloy producing and using industries, of the 580.9 million pounds of scrap generated from these six alloy classes in 1976, about 72 percent (416.8 million pounds) was remelted by the same alloy-producing industries, about 18 percent (104.9 million pounds) was downgraded into stainless steel and low-alloy steels, about 3 percent (19.7 million pounds) was exported, and about 7 percent (39.5 million pounds) was lost through landfill disposal. The lost material is primarily contaminated oxides which currently are unrecoverable. However, the 124.6 million pounds of scrap material estimated to be downgraded or exported in 1976 contained potentially recoverable critical strategic elements.

The quantities of chromium, nickel, cobalt, iron, and other elements contained in scrap that is currently remelted, lost, downgraded, or exported are given in table 30. From this it can be shown that a significant amount of chromium (22.1 million pounds) was downgraded or exported in 1976. Recovery of this chromium and other strategic metals would provide a significant quantity of the primary metals needs of these alloy-producing industries.

CONCLUSIONS

1. A production model that defines the flow of materials from raw materials to obsolete scrap has been established for six related alloy classes produced by the superalloy and heat- and corrosion-resistant alloy casting industries.

2. Scrap has been identified according to quantity, alloy class, physical form, grade or quality, origin, and destination.

3. The quantity and quality of scrap used for recycling and the procedures for using it are different for each alloy class. Generally, the requirements are most stringent for the high-nickel alloys, which use the purest and most costly form of primary chromium and the least amount of scrap.

4. The total quantity of scrap generated in the production and use of these alloys in 1976 was 580 million pounds containing 113.2 million pounds of chromium. Approximately 125 million pounds of scrap containing about 25 million pounds of chromium was downgraded or exported. About 40 million

pounds of scrap containing 7.4 million pounds of chromium was physically lost or considered as waste that was too contaminated to recover.

5. About 78 percent of the melt charge for heat- and corrosion-resistant alloy castings is scrap. This represents all of the available scrap of suitable quality for that class; hence, there is little prospect for further improvement in recycling efficiency.

6. The current recycling efficiency for the other higher alloy classes is much lower (37 to 60 percent) owing to metallurgical constraints. Research aimed at improving recycling efficiency for these alloy classes would reduce the quantity of high-grade scrap now downgraded or exported.

7. The model developed in this study could provide the basis for continued surveillance of the field to develop a more comprehensive data base.

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APPENDIX A.--DEFINITION OF TERMS

Aerospace Industry.--Manufacturers of airplanes, rockets, and attendant equipment.

Air-Melt-Grade Scrap.--Mixed scrap of known alloy type, generally in solid form but may include turnings.

Charge Materials (Melt Charge).--Raw materials to be melted to provide an ingot or casting. Includes primary metals, purchased scrap, and home scrap.

Continuous Casting.--A method of forming a bar or slab by continuously pouring molten metal through a nozzle into an open-ended mold. Solid metal is withdrawn continuously from the exit side of the mold.

Corrosion-Resistant Alloy Castings.--Cast alloys used to resist corrosion by aqueous solutions at or near room temperature and hot gases at temperatures to 1,200° F. Includes those alloys defined as C-grades by the American Casting Institute.

Downgraded Scrap.--A highly alloyed scrap metal used in the preparation of a less complex alloy (for example, a nickel-base alloy used as a component in a stainless steel charge).

Dust.--Fine, metal-containing particles formed during melting and working operations such as those collected in baghouses and electrostatic precipitators. These are usually fully oxidized and contain volatile impurities and nonmetallic elements.

Equipment Life Cycle.--The average time period for which a particular part is expected to last in service prior to wearing away, corroding, or becoming inefficient.

Exported Scrap.--Scrap metal that is generated in the United States and exported for sale outside the United States.

Fabricator.--Organization that transforms a previously cast and/or wrought metal (primary product) into a finished product.

Finished Product.--A completed part or structure that is ready for service.

Grindings.--Scrap generated during the removal of metal by an abrasive wheel or belt. The waste includes particles of the metal being ground and the abrasive. Frequently they are contaminated with oil.

Hardfacing.--Depositing metal on a surface by welding, spraying, or braze welding for the purpose of resisting abrasion, erosion, wear, corrosion, galling, or impact.

Heat-Resistant Alloy Castings.--Cast alloys that are capable of sustained operation at temperatures in excess of 1,200° F. Includes those alloys designated as H-grades by the American Casting Institute.

Home Scrap.--Scrap generated by an alloy producer during the conversion of raw materials to primary product. Home scrap includes solids, turnings, grindings, skulls, slag, scale, and dust.

Identified Scrap.--Scrap of known single-alloy designation. Generally only solids fall into this classification, and they are usually vacuum grade.

Intrinsic Metal Value.--The value of a quantity of scrap based on the current primary metal price of the individual alloying elements.

Investment Casting.--Casting metal into a mold produced by surrounding an expendable pattern with a refractory slurry; the pattern is eventually removed by melting. Also known as precision casting and the lost wax process.

Liquor.--Spent liquids from pickling, electroplating, and cleaning operations.

Lost Scrap.--Dust, scale, slag, pickle sludge, electrochemical and electrodischarge machining wastes, and service wastage which are unsuitable for remelting or refining and are currently disposed of as landfill. In addition, this category includes lost solid scrap metal.

Master Melt.--An alloy prepared for remelting by a foundry. Often produced and sold by firms specializing in the business. Generally used as the melting stock for foundries making investment castings.

Merchant Price.--Prices quoted by metal merchants or traders for primary metals and scrap. Prices vary according to market conditions and may be either higher or lower than producer price. Merchant prices for major primary metals are recorded on the commodity exchanges.

Mixed Melt Shop Scrap.--Skulls and spills in which the solidified metal has trapped with it a significant amount (perhaps 10 percent) of refractory oxides, dust, or scales. These usually are not identified as to exact composition, but are identified by alloy class.

Near Net Shape Processing.--A process that produces an intermediate shape as close to final part dimensions as possible to minimize metal removal. Powder metallurgy and casting are examples.

Obsolete Scrap.--Solids and grindings that occur when used equipment is overhauled or dismantled, and service wastage which occurs during the lifetime of the equipment.

Primary Metal.--A raw material derived directly from ore that is used either by itself or with scrap to prepare a charge for melting. This category includes all new metals used during melting such as vacuum-grade chromium, ferrochromium, and electrolytic nickel.

Primary Product.--Cast or wrought, semifinished material prepared by an alloy producer. Includes master melt, sheet, plate, strip, bar, tubing, forging stock, welding products, powder, and rough castings.

Producer.--Organization that converts raw materials in the form of primary metals, purchased scrap, and home scrap into a cast or wrought form known as a primary product.

Producer Price.--Price that a primary metal producer quotes for a product. Price statistics are usually published and recorded by publications such as American Metal Market.

Production Efficiency.--A measure of output as compared to starting materials at any stage of the life cycle of a part.

Production Model.--A mass balance model describing metals flow from raw materials through obsolete scrap.

Prompt Industrial Scrap.--Scrap generated by a fabricator or manufacturer during conversion of a primary product to a finished product at a location removed from the melting facility. This generally takes the form of clippings and punchings from sheet metal, turnings, and solids from heavier castings and wrought products and grindings, sludges, and liquors from finished operations.

Purchased Scrap.--A raw material used for melting having an origin outside the melt shop. This form of scrap may be purchased from another alloy producer, from a manufacturer, or as obsolete parts and can be obtained directly from these sources or through an intermediary.

Raw Materials.--The basic materials needed for melting an alloy; that is, the metallic constituents, including primary metals, home scrap, and purchased scrap.

Recyclers.--Organizations that collect, classify, and redistribute industrial wastes and obsolete equipment for the purpose of recovering valuable constituents. Recyclers include scrap dealers and brokers, reprocessors, and secondary refiners.

Refinery-Grade Scrap.--Mixed turnings and solids of unknown composition, oxides, grindings, etc., that are generally unsuitable for remelting without refining.

Remelted Scrap.--Solids, grindings, and turnings that are used as part of the raw material charge for melting.

Same-Alloy Scrap.--Homogeneous scrap of known composition that is to be remelted into a new alloy of the same designation. Little or no composition adjustment would be needed to meet alloy specification.

Scale.--Metallic oxides that form on the surface of metals during elevated-temperature exposure, generally produced during hot working or heat treating; they are of mixed composition and are often contaminated with oil.

Secondary Metals.--Pure metals or master alloys prepared by a refiner from scrap. In some cases secondary metals may be metallurgically indistinguishable from primary metals. The distinction is further blurred by primary metal producers who introduce scrap metal into their refinery circuit.

Service Wastage.--Generally unrecoverable loss of metal during service, caused by wear, spalling, oxidation, corrosion, etc. Also includes materials that are unrecoverable because of the nature of their service; that is, certain military hardware, nuclear power system components, and general consumer items such as appliance heating elements and automotive parts.

Skulls.--A layer of solidified metal on the walls of a furnace, ladle, tundish, or mold. This solid scrap usually has a significant amount of refractory oxide associated with it.

Slag.--A mostly nonmetallic product resulting from the mutual dissolution of flux and nonmetallic impurities in smelting and refining operations. Slags often contain valuable metal dissolved as oxide or physically trapped as small metallic droplets.

Sludge.--Scrap produced by electroplating, pickling, polishing, electrochemical machining, and other industrial operations. Sludge generally has a low metal content and contains large quantities of chemical salt, oil, or water.

Solids.--A classification for articles larger than about ¼-inch diameter. Includes casting scrap (misruns, gates, risers, imperfect castings), ingot hot tops, billet cropping, clippings, obsolete parts, etc.

Spills.--Solidified drops and splashes of metal formed inadvertently during the pouring of molten metal. This solid scrap usually has a significant quantity of refractory oxide, dust, and scale trapped within it.

Superalloy.--A general definition used for chromium-containing alloys based on nickel, cobalt, or iron developed for elevated temperature service where severe mechanical stressing is encountered and where surface stability is frequently required. Wrought heat-resisting stainless steels (>55 percent iron) are excluded from this classification.

Trace Element.--Small quantity (<0.1 percent) of an element known to degrade the physical or mechanical properties of an alloy. Also commonly referred to as tramp and subversive elements. Many elements, including phosphorus, sulfur, lead, and tin, adversely affect the properties of nickel-base alloys.

Turnings.--A classification for scrap generated by machine tool operations. Examples are turnings from lathes and chips from milling machines and shapers. All turnings may contain cutting oil and are usually cleaned, fragmented, and compacted by recyclers.

Underutilized.--Refers to scrap of a particular alloy class that is not remelted in that class, but for reasons of geography and/or economics and/or form is used to prepare a different class of alloy (downgraded) or is discarded.

User.--An organization that uses a finished product until the product is retired from service owing to wear, corrosion, or inefficiency and/or is considered to be obsolete. Includes aerospace, transportation, petrochemical, and energy conversion industries.

Vacuum-Grade Scrap.--Scrap of the highest quality that is of known origin, identity, and composition. This form of scrap has not necessarily been previously vacuum-melted nor need it be used again in a vacuum furnace.

Waste.--Materials generated during production and service that are not currently recovered. Includes dusts, floor sweepings, wear and corrosion products, and metals contaminated with salt, oil, or tramp elements or in a very dilute concentration such that they cannot now be economically recovered.

APPENDIX B.--DEVELOPMENT OF MATERIALS FLOW MODEL

In the metals producing and using industries, it is possible to simplify an exceedingly complex system (number of alloys, production practices, and uses) by a materials flow diagram. The diagram shown in figure 1 represents a mass balance for these industries. This model has four discrete elements: raw materials, primary product, finished product, and scrap material. Each of these elements can be characterized in terms of the quantity and character of input and output materials.

General Description of Model

The following section summarizes how the production model was developed and used. Alloy classes were defined based on ranges of composition of Cr, Ni, Co, and Fe and distinct characteristics of the producing industries. Production practices, quantity of Products and scrap produced at each stage of production, and the character and disposition of scrap generated were all estimated, based on published information, Inco experience, and a selective industry survey.

First, the quantity and average composition of primary production for 1976 were estimated. Second, the alloy producers provided an estimate of their efficiency of production and the relative quantity of primary metal, purchased scrap, and home scrap used to produce these primary products. The alloy producers also characterized and estimated the quantities of scrap generated during their production cycle. From this information estimates were made of the quantity of home scrap that was recycled internally, downgraded, exported, or lost.

Next, the finished-product manufacturing cycle was examined. Through discussions with manufacturers and industry experts, an estimate was made of the overall efficiency of utilization of primary product in manufacturing the finished product. From this, it was possible to calculate the quantity of finished product and quantity of scrap generated during the base year. These same sources were asked to characterize the scrap generated during the finished-product manufacturing cycle and to provide estimates of the relative quantities and disposition of this prompt industrial scrap.

Finally, end users, scrap dealers, and industry experts provided estimates of the average life cycle, and indicated scrap practices for obsolete equipment. An estimate was made of the average life cycle of components made of alloys from each class, the amount of service wastage, and the character, quantity, and disposition of the obsolete scrap generated when the finished products were removed from service.

This model was developed, for each of the six alloy classes covered in this study, by gathering data and information from many of the producers and users of the alloys and products. The model is applied to the wrought nickel- and cobalt-base alloy class in the following discussion for demonstration purposes.

Model Applied to Wrought Nickel and Cobalt Alloy Class

Defining the Alloy Class

The initial step in developing the production model is to define the alloy class. For the wrought nickel- and cobalt-base alloys, the ranges of Cr, Ni, Co, and Fe are as follows: 15 to 25 percent Cr, 0 to 80 percent Ni, 0 to 80 percent Co, and 0 to 20 percent Fe.

Compositions of typical alloys included in this class are given in table C-2. The production of these alloys is confined to a relatively small number of companies that have specialized facilities for melting and hot working.

Quantity of Primary Product

Experience has shown that the information that can be most accurately defined within a production circuit for a given year is the quantity of primary product. This quantity was the starting point in developing quantitative data in the production model. Because there is no comprehensive reporting of production data for this class of alloys, an estimate based on a variety of data sources was made. For the wrought nickel- and cobalt-base alloy class, 1976 production was estimated at 90 million pounds. Further, estimates were made of the quantity of specific alloys produced within this alloy class (table 4). Combining the information in tables 4 and C-2, it was possible to calculate the average composition for the alloy class: 62.5 percent nickel, 18.2 percent chromium, 7.0 percent iron, 4.8 percent cobalt, and 7.5 percent other elements. This composition is representative of the raw materials that go into making up the melt charge and of the products and scrap generated throughout the production circuit.

Constituents of the Raw Materials Charge

The second step in developing quantitative data for the model was to estimate the quantity and makeup of the raw materials for melting. This could be done in one of two ways. First, detailed data on specific alloys and producers could be compiled to determine total raw materials used. However, it was found that this type of specific information was not available from many alloy producers and that available data are unreliable because raw materials inventories vary widely. An alternative approach, suggested by several alloy producers, was to estimate the average efficiency of production for each class of alloy. The figure for the wrought nickel- and cobalt-base alloy class derived from the survey was 50 percent. Thus, production of 90 million pounds of wrought nickel- and cobalt-base alloys in 1976 required melting and processing of 180 million pounds of raw materials.

The alloy producers were asked to identify the types of raw materials used for melting. The responses showed that, on average, the raw materials charge consisted of 40 percent (72 million pounds) primary metal, 13 percent (23.4 million pounds) purchased scrap, and 47 percent (84.6 million pounds) home scrap. The purchased scrap was estimated to be 100 percent solids,

derived from prompt industrial and obsolete scrap. The industry currently recycles all of the solids and turnings generated as home scrap.

Characterization of Home Scrap

From the raw materials and primary product differential, it was estimated that 90 million pounds of home scrap was generated in producing 90 million pounds of wrought nickel- and cobalt-base alloy primary product in 1976. Based on the information provided by the alloy producers, it was estimated that home scrap consisted of 44 percent (79.2 million pounds) solids, 3 percent (5.4 million pounds) turnings, 1.5 percent (2.7 million pounds) grindings, 0.5 percent (1.0 million pounds) mixed skulls, spills, etc., and 1.0 percent (1.7 million pounds) waste.

The alloy producers indicated that the solids and turnings were recycled within the melt shop, the waste material was disposed of in landfills, and the grindings and mixed scrap were sold to dealers or secondary refiners. Virtually all of this material is believed to be downgraded, and much of the contained chromium and other metals is lost.

Quantity of Finished Product

Next, an estimate based on production efficiency was made of the quantity of finished product derived from the primary product. Based on various data sources (including direct inquiries), it was determined that production efficiency at this stage is 54 percent. Thus 48.6 million pounds of finished product (heat exchanger, chemical process equipment, gas turbine, etc.) was produced in 1976.

Character of Prompt Industrial Scrap

Inquiries were made regarding the character of the scrap produced during finished-product manufacture. It was estimated that the 41.4 million pounds of prompt industrial scrap consisted of 46 percent (18.9 million pounds) turnings, 30 percent (12.6 million pounds) solids, 17 percent (7.2 million pounds) grindings, and 6.5 percent (2.7 million pounds) wastes.

Regarding disposition of prompt industrial scrap, it was estimated that 5.4 million pounds of solids was recycled as purchased scrap by the wrought nickel- and cobalt-base alloy producers, either through direct sales or indirectly through dealers. The remaining usable prompt industrial scrap sold to scrap dealers and refiners was exported or downgraded. The 1.5 percent waste was disposed of in landfills.

Character of Obsolete Scrap

Manufacturers and scrap dealers were consulted to define the life cycle, service wastage, and decommissioning procedures for obsolete equipment containing wrought nickel- and cobalt-base alloys. From the responses to these inquiries, it was estimated that the average lifetime of these alloy components in such equipment (gas turbine components, heat exchangers, and chemical

and process heat equipment) is 10 years. Thus the 48.6 million pounds of finished product produced in 1976 will become a similar quantity of obsolete scrap in 1986. The obsolete scrap available for remelting in 1976 was estimated from 1966 primary production by assuming that production efficiencies were the same in both years. Therefore, the quantity of obsolete scrap in 1976 was 38.4 million pounds. Service wastage due to wear, corrosion, and misplacement accounted for a loss of material equal to 7.5 percent of the original manufactured product or 2.8 million pounds. The obsolete equipment yielded 33.5 million pounds (8.7 percent) of solids and 2.1 million pounds (5.5 percent) of grindings.

Of the obsolete scrap, it was estimated that 14.2 million pounds of solids was recycled to the wrought nickel- and cobalt-base alloy producers, primarily through indirect sales. The remaining 19.2 million pounds of solids and 2.1 million pounds of grindings was sold for export or downgrading. The 2.8 million pounds of waste material was lost to the environment.

APPENDIX C.--CHEMICAL COMPOSITIONS OF SPECIFIC ALLOYS

This appendix presents the chemical compositions of some of the specific alloys that are considered to fall within the six broad alloy classes covered in this study. Hardfacing cast nickel-base and cobalt-base alloys were not included because of the many proprietary compositions which exist. An average cobalt-base composition and an average nickel-base composition are presented in table C-3.

Frequent mention of specific alloys is made in this report. It will be readily seen that the six alloy classes surveyed are characterized by a large number of alloy compositions and designations, many of which are proprietary. Many companies apply a numerical system appended to a trade name for identification of their alloys. In some cases, the numbers are dropped in popular usage and the trade names are applied to the most common alloys; for example, INCONEL alloy 600 is often simply referred to as INCONEL, even though this usage is discouraged by the producer. This report identifies alloys by correct trade name designations when it is necessary for understanding the industry. In some cases, the alloys are produced by more than one company under license, but are still most often referred to by the trade name of the licensor. Use of these designations does not imply endorsement of the alloy or producer by either the Bureau of Mines, The International Nickel Co., Inc., or the authors of the report.

The following list gives the owners of alloy trade names referred to in this report.

ARMCO--Armco Steel Corp.
HASTELLOY--Cabott Corp.
INCOLOY--Huntington Alloys, Inc.
INCONEL--Huntington Alloys, Inc.
PYROMET--Carpenter Technology Corp.
RA 330--Rolled Alloys, Inc.
RENÉ--General Electric Co.
RENÉ--Teledyne Allvac.
UDIMET--Allegheny Ludlum Industries.
WASPALOY--United Technologies, Inc.

TABLE C-1. - Compositions of cast nickel- and cobalt-base alloys

Alloy designation	Nominal composition,[1] weight-percent										
	Cr	Ni	Co	Fe	Mo	W	Ta	Cb	Al	Ti	Hf
Alloys 713C and 713LC	12.3	74.6	NAp	NAp	4.2	NAp	NAp	2.0	6.1	0.8	NAp
B-1900+Hf............	8.0	65.0	10.0	NAp	6.0	NAp	4.0	NAp	6.0	1.0	1.0
RENÉ.................	14.6	58.6	15.0	NAp	4.2	NAp	NAp	NAp	4.3	3.3	NAp
X-40.................	25.5	10.5	56.5	NAp	NAp	7.5	NAp	NAp	NAp	NAp	NAp
INCONEL alloy 738....	16.0	61.8	8.5	NAp	1.7	2.6	1.7	.9	3.4	3.4	NAp
INCONEL alloy 718....	19.0	52.9	NAp	18.5	3.0	NAp	NAp	5.2	.6	.8	NAp
FSX-414..............	29.0	10.0	52.5	1.0	NAp	7.5	NAp	NAp	NAp	NAp	NAp
WI-52................	21.0	NAp	69.5	2.0	NAp	7.5	NAp	NAp	NAp	NAp	NAp

NAp Not applicable.
[1]Nickel- and cobalt-base alloys may also contain minor quantities of carbon, manganese, silicon, boron, zirconium, and other elements.

TABLE C-2. - Compositions of wrought nickel- and cobalt-base alloys

Alloy designation	Nominal composition,[1] weight-percent								
	Cr	Ni	Co	Fe	Mo	W	Cb	Al	Ti
INCONEL alloy 600...........	15.5	76.5	NAp	8.0	NAp	NAp	NAp	NAp	NAp
WASPALOY....................	19.5	58.4	13.5	NAp	4.3	NAp	NAp	1.3	3.0
INCONEL alloy 718...........	19.0	53.0	NAp	18.5	3.0	NAp	5.1	.5	.9
INCONEL alloy 750...........	15.5	73.3	NAp	7.0	NAp	NAp	1.0	.7	2.5
INCONEL alloy 751...........	15.5	72.5	NAp	7.0	NAp	NAp	1.0	1.2	2.5
INCONEL alloy 700...........	15.5	46.3	29.0	NAp	3.8	NAp	NAp	3.3	2.6
UDIMET 500..................	18.0	53.7	18.5	NAp	4.0	NAp	NAp	2.9	2.9
UDIMET 700..................	15.0	52.0	18.5	1.00	5.0	NAp	NAp	4.2	3.5
RENÉ 41.....................	19.0	55.4	11.0	NAp	10.0	NAp	NAp	1.5	3.1
HASTELLOY alloy X...........	22.0	48.4	1.5	18.5	9.0	0.6	NAp	NAp	NAp
HASTELLOY alloy C-276.......	15.5	57.2	2.0	5.5	16.0	3.8	NAp	NAp	NAp
RENÉ 95.....................	14.0	Bal.	8.0	1.0	3.5	3.5	3.5	4.4	2.5

NAp Not applicable.
[1]Nickel- and cobalt-base alloys may also contain minor quantities of carbon, manganese, silicon, boron, and zirconium. Figures for Cb include Ta.

TABLE C-3. - Compositions of wrought nickel-iron-base alloys

Alloy designation	Nominal composition,[1] weight-percent										
	Cr	Ni	Co	Fe	Mo	W	Cb	Al	Ti	Mn	Si
INCOLOY alloy 800..	21.0	32.5	NAp	44.4	NAp	NAp	NAp	0.4	0.4	0.8	0.5
INCOLOY alloy 801..	20.5	32.0	NAp	44.5	NAp	NAp	NAp	NAp	1.1	.8	.5
INCOLOY alloy 802..	21.0	32.5	NAp	46.0	NAp	NAp	NAp	.6	.8	.8	.4
INCOLOY alloy 825[2].	21.5	42.0	NAp	30.0	3.0	NAp	NAp	.1	.9	.5	.3
INCOLOY alloy 901..	12.5	42.5	NAp	36.1	5.7	NAp	NAp	.2	2.8	.1	.1
INCOLOY alloy 903..		38.0	15.0	Bal.			3.0	.7	1.4		
A-286..............	15.0	26.0	NAp	53.6	1.3	NAp	NAp	.2	2.0	1.4	.5
ARMCO 20-45-5......	20.0	45.0	NAp	27.2	2.2	NAp	.2	NAp	NAp	4.0	.4
V-57...............	14.8	27.0	NAp	52.4	1.3	NAp	NAp	.3	3.0	.4	.8
N-155..............	21.0	20.0	20.0	30.5	3.0	2.5	1.0	NAp	NAp	1.5	.5
RA 330.............	19.0	35.0	NAp	43.0	NAp	NAp	NAp	NAp	NAp	1.5	1.2
PYROMET 860........	12.6	43.0	4.0	30.0	6.0	NAp	NAp	1.2	3.0	.1	.1

NAp Not applicable.
[1]Nickel-iron-base alloys may also contain minor quantities of carbon, boron, and zirconium.
[2]Also contains 2.25 percent copper.

TABLE C-4. - Compositions of major heat- and corrosion-resistant alloy castings

Alloy designation	Nominal composition,[1] weight-percent		Alloy designation	Nominal composition,[1] weight-percent	
	Cr	Ni		Cr	Ni
HK............	26	20	HU............	39	19
HH............	26	12	HN............	25	20
HT............	15	35	HL............	30	20
HC............	28	4	HF............	20	10
CF-8M[2].........	20	10	HD............	28	5
CF-8..........	20	10	CA-6NM.........	12	4
CA-15.........	12	1	CF-3M[2].........	20	10
CN-7M.........	20	26	CD-4MCu[3].......	26	5
CB-30.........	20	2	CF-8C[4].........	20	10
HP............	26	35	CA-40.........	12	1 (max)

[1]Heat- and corrosion-resistant alloy castings may also contain minor quantities of carbon, manganese, and silicon. The balance of the composition is iron.
[2]Also contains 2.5 weight-percent Mo.
[3]Also contains 2 percent Cu.
[4]Also contains Cb; 8xC min, 1.0 percent max.

APPENDIX D.--COMPANIES AND ORGANIZATIONS CONTACTED DURING THIS STUDY

Name	Category[1]
Abex Corp	AP, CP
Air Force Materials Laboratory	GA, EH
AiResearch Manufacturing Co	GTM, PM
Alloy Engineering & Casting Co	AP, CP
Avco Lycoming Division	GTM
Brown Boveri Turbomachinery, Inc	GTM
Cabot Corp	AP
Cannon-Muskegon Corp	AP, CP
Carondolet Foundry Co	AP, CP
Carpenter Technology	AP
Certified Alloy Products, Inc	AP, CP
Chromalloy Corp	AP, PM
Chyrsler Corp	GTM, PM
Detroit Diesel Allison Division	GTM, PM
Duraloy Blaw-Knox Inc	AP, CP
Eaton Corp	PM
Electralloy Corp	AP, SR
Ferroalloys Producers Association	PIA
Ford Motor Co	GTM, PM
General Electric Co	GTM, PM
General Motors Corp	GTM, PM
Howmet Turbine Components Corp	AP, CP
Huntington Alloys, Inc	AP
Inco Metals Co., Inc	MP
International Metals Reclamation Co., Inc	AP, SR
International Nickel Co., Inc	MP
Jet Shapes, Inc	CP
Kokomo Tube Co	AP, CP
Ladish Corp	F
Levin Metals Corp	SD, SR
Martin-Marietta Corp	AP, PM
National Aeronautics and Space Administration	GA, EH
National Association of Recycling Industries, Inc	PIA
Precision Castparts Co., Inc	AP, CP
Prestige Metals Co	SD, SR
RSC Materials Technology Associates, Inc	C
Samuel Keywell, Inc	SD, SR
Samuel Zuckerman and Co	SD, SR
Shieldalloy, Inc	AP, MP
Solar Turbines International	GTM
Special Metals Co	AP, CP
Suissman and Blumenthal, Inc	SD, SR
Teledyne Allvac	AP
Teledyne Ohiocast	AP, CP
TRW, Inc	AP, CP
United Airlines, Inc	EH
U.S. Department of the Interior, Bureau of Mines	GA
United Technologies, Inc	GTM, PM, AP, CA
Universal Cyclops Corp	AP
Westinghouse Electric Corp	GTM, PM
Williams Research Corp	GTM
Wisconsin Centrifugal, Inc	AP, CP
Wyman-Gordon Co	F

[1]AP: Alloy producer; C: Consultant; CP: Castings producer; EH: End user; F: Forger; GA: Government agency; GTM: Gas turbine manufacturer; MP: Metals producer; PIA: Private industrial association; PM: Product manufacturer; SD: Scrap dealer; SR: Scrap recycler

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